NASA CR-72190
AEROJET-3335

SNAP-8 ELECTRICAL GENERATING SYSTEM DEVELOPMENT PROGRAM

PROGRESS REPORT FOR OCTOBER - DECEMBER 1966

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER

CONTRACT NAS 5-417

VON KARMAN CENTER
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

Requests for copies of this report should be referred to:

NASA Scientific and Technical Information Facility
P.O. Box 33
College Park, Maryland, 20740

NASA CR 72190
Aerojet 3335

QUARTERLY PROGRESS REPORT FOR OCTOBER-DECEMBER 1966

SNAP-8 ELECTRICAL GENERATING SYSTEM DEVELOPMENT PROGRAM

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 1967

CONTRACT NAS 5-417

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
SNAP-8 Project Office
H. O. Slone, Manager

Von Karman Center
AEROJET-GENERAL CORPORATION
Azusa, California

CONTRACT FULFILLMENT STATEMENT

This quarterly progress report is submitted to the National Aeronautics and Space Administration in partial fulfillment of Contract NAS 5-417. This report covers the period from 1 October through 31 December 1966.

APPROVED:

Robert Gordon

Robert Gordon, Manager
Power Systems Division
Aerojet-General Corporation

ABSTRACT

SNAP-8 is a turboelectric, nuclear, space power conversion system using a mercury Rankine cycle. The system incorporates three liquid metal loops. Sodium-potassium (NaK) in a primary loop is heated in a reactor, and, in turn heats mercury in a heat exchanger. The mercury vapor, in the second loop, expands through a turbine; it is then condensed, and pumped back through the boiler. A third loop, also containing NaK, transfers the heat from the mercury to a radiator where it is rejected to space. The fourth loop contains a polyphenyl ether that lubricates the bearings of the main rotating components and provides necessary cooling for the alternator, electric motors, and controls.

This report discusses the development progress of the power conversion system (turbine-alternator assembly, pump-motor assemblies, boiler, condenser, and electrical controls), and the progress in system testing during the fourth quarter of 1966.

NASA STAR Category 03

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

I. INTRODUCTION

The SNAP-8 electrical generating system is being developed by the National Aeronautics and Space Administration for use in various space applications. The system provides 35 kw of electrical power by converting heat from a nuclear reactor into electrical energy. Aerojet-General Corporation is developing the SNAP-8 power conversion system at its Von Karman Center in Azusa, California, under NASA Contract NAS 5-417. The nuclear reactor is being built for the Atomic Energy Commission by Atomics International, Inc.

SNAP-8 is a turboelectric, nuclear, space power conversion system using a mercury Rankine cycle. The system incorporates three liquid metal loops. Sodium-potassium (NaK) in a primary loop is heated in a reactor, and, in turn heats mercury in a heat exchanger. The mercury vapor, in the second loop, expands through a turbine; it is then condensed, and pumped back through the boiler. A third loop, also containing NaK, transfers the heat from the mercury to a radiator where it is rejected to space. The fourth loop contains a polyphenyl ether that lubricates the bearings of the main rotating components and provides necessary cooling for the alternator, electric motors, and controls.

This report is the second in a series of Quarterly Progress Reports, and includes a discussion and evaluation of the technical progress during the period 1 October through 31 December 1966. This series of reports replaces the Semiannual Progress Reports that were published during 1965 and the first half of 1966.

II. COMPONENT DEVELOPMENT

A. TURBINE-ALTERNATOR ASSEMBLY (TAA)

In this report period, the redesign of the turbine hot parts has continued. Fabrication of rotor wheels and nozzle assemblies for the improved aerodynamic design was started.

TAA 1/4 was delivered to PCS-1 for the Step 3 startup tests. This unit includes an all S-816 2nd-stage nozzle assembly and thus will provide the first opportunity to evaluate this material in the SNAP-8 turbine under design environment conditions. TAA 6/2 was inspected and shipped to NASA LeRC on 19 October 1966.

1. Design

a. Nozzle assembly design

(1) Second-stage nozzle assembly

(a) Stress Analysis

The second-stage nozzle assembly has been redesigned and thermal and stress analyses conducted. The stress analyses have been conducted on the basis of forces applied to the diaphragm as a result of (1) the axial differential pressure load, and (2) the loading caused by the thermal gradients which occur radially, circumferentially, and axially during start transients. The thermal analysis and resulting temperature map were based upon surface mercury condensing film coefficients of 10,000 Btu/hr/ft^2/^{o}F and 100 Btu/hr/ft^2/^{o}F on the upstream and downstream sides of the nozzle assembly, respectively. This information was used in the stress analysis described below.

Initially, the stress analysis conducted on the assembly was a hand analysis based upon the application of strain energy theory and the use of internal restraints. While this hand analysis was in progress, a finite element computer-program stress analysis was initiated in order to supplement the hand calculations. The computer program was developed by AGC for the determination of displacements and stresses within plane and axisymmetric solids with linear and nonlinear properties and is discussed in References 1, 2, and 3.

The results of the two methods of stress analysis, however, were very different in stress level and the point at which the maximum stress occurred. For example, the rigorous internal restraint and strain-energy calculation indicated maximum stress levels of the order of 48,000 lb/in.^{2}. This maximum stress occurred close to the bend of the U - shaped shroud. The initial results of the computer program indicated much higher stress levels (171,000 lb/in.^{2}) occurring at the OD of the diaphragm at the juncture of the shroud and diaphragm at the knife edge (trailing edge) of the window.

In both analyses, the stress levels were due largely to the reaction between the diaphragm and shroud. The extremely high stress level indicated by the computer program was later revealed to be the result of an erroneous input to the program. The computer program was applied, using a ring supposedly having elastic properties equivalent to that of the shroud. However, the ring used did not take into account the flexibility resulting from the presence of the vane slots on the outer diameter of the diaphragm. With the increased flexibility, it is expected that the stress level indicated by this computer program will be considerably lower. The stresses are in the process of being recomputed, using a more realistic shroud flexibility. Both stress analyses indicated that some degree of yielding will occur.

A factor that is still clouding the veracity of the calculated stresses is the properties of the 19-9DL material to be used in the second-stage nozzle assembly design. At present, little information has been found regarding high-temperature strain and creep characteristics. Tests on this material are presently being planned.

(b) Thermal shock test

In view of the difficulty of accurately predicting the transient thermal environment and, consequently, the thermal map, an empirical approach was used in arriving at a relatively simple ranking test. The basis of the tests would be to fail the current Stellite 6B second-stage diaphragm in the same manner as it has failed during TAA testing and then subject the new design to a thermal shock at a much higher temperature.

Realistic conditions with regard to film coefficient and thermal gradients were produced by immersing the nozzle assembly in a hot lead bath. This test is performed by subjecting an instrumented diaphragm to increasing temperature differences until failure occurs; the tested parts are masked to create severe thermal gradients. The major objective of this thermal shock test is to demonstrate the acceptability of the new nozzle diaphragm assembly. The tests were initially conducted on a dummy diaphragm to check out the instrumentation and test procedure. A Stellite 6B diaphragm assembly (current design) has been subjected to temperature differentials ranging from room temperature to 1100°F and no failure has occurred.

Examination of the results (Figures II-1 and II-2 indicate that, in general, the temperature vs time curves have shapes that are similar to those predicted by thermal analysis. These also reveal certain anomalies which provide the answer as to why the part has not, and should not fail with the present test setup. From curves shown in Figure 2, it can be seen that:

1 The temperature of the lead in the geometric center of the window (T-10) fell very rapidly during the first 10 seconds to temperatures below 621°F (the melting point of lead). It then increased gradually toward the steady-state temperature. Fluctuations in the maximum initial temperature of the lead (T-10) may be attributed to uneven stirring of the lead bath during each trial.

2 During the "200°F preheat and the 700°F lead bath temperature" trial, the temperature on the outer surface of the shroud (T-9) exceeded the temperature of the lead in the window area (T-10) from t = 35 seconds until t = 115 seconds. This phenomenon does not agree with physical reasoning and casts doubt upon the validity of the temperatures at T-9 and/or T-10.

3 The initial drop in temperature of T-10 below the melting point confirms that, initially, solidification of the lead on all exposed surfaces does occur. This implies the existence of a "lead boundary layer" which offers a considerable thermal resistance to the flow

of heat to the diaphragm-shroud assembly. Thus, the assembly is, in effect, exposed to lead bath temperatures which are approximately 200°F lower than the mean lead-bath temperature.

Furthermore, it would appear that the masking of the region of the diaphragm and the shroud not exposed to the hot lead was not ideal. In addition, it is obvious that present masking of the shroud does not provide a realistic heat sink as it appears that the shroud heats up almost as rapidly as the diaphragm and is in fact "growing" away from the diaphragm during the transient. Thus, no diaphragm-shroud interaction (and consequent high stresses) could occur. As a result of these findings, the diaphragm masking is being modified and heat transfer salt (HTS) will be put into the shroud OD mask (this will provide a larger heat sink and keep the shroud cooler for a longer period) and the tests repeated at the beginning of the next report period.

(2) Third-stage nozzle assembly

Thermal maps (obtained in the same manner as described for the second stage) for these assemblies produce much less severe temperature gradients than experienced by the second stage; consequently, stress levels were expected to be much lower.

The stress analysis for the third-stage nozzle assembly indicated a maximum stress level of 63,000 psi, occurring near the location of the labyrinth seal recess at the diaphragm hub. The analysis also indicated that localized yielding will occur. However, the mathematical model of the nozzle assembly used in the computer program was such as to give stress levels higher than would be experienced by the actual configuration. The levels were considered acceptable. The possibility of permanent distortion was considered and it became apparent that this condition would apply additional loads to the roll pins. The effect of the distortion and pin loading will be investigated.

(3) Fourth-stage nozzle assembly

The stress analysis conducted for this nozzle assembly was simplified by the assumption that the diaphragm was a flat plate.

However, the actual shape of a small cross section at the OD of the diaphragm is conical with an included angle of 148°. The simplified stress analysis indicated values less than half the yield of the material. On this basis, it is considered that an ample margin of safety exists.

(4) Start seal liftoff device (prototype)

A specification control drawing for the device was released. In conjunction with this design, a closed loop fluid with a central bellows device will be investigated within the liftoff system. In this manner, the leakage of the liftoff bellows would not cause a loss of working fluid in the system. Long-life capabilities of the carbon nose piece, when subjected to a high vacuum, are being investigated in addition to considering the use of a material other than carbon for the nose piece.

(5) Labyrinth seals (thrust and interstage)

An alternate design of labyrinth seals was evaluated. This design was based on the hydrostatic bearing principle. However, due to close clearance control requirements and instability problems, the design was not pursued further. However, other related work is proceeding as follows: (a) dynamic analysis of shaft, bearing, and housing; (b) housing deflection test; and (c) shaft dynamic test proposal.

2. <u>Turbine Design Review</u>

The two design reviews held during this report period on the new turbine design have resolved the following; (a) aerodynamics of the turbine, (b) materials for the mercury exposed parts, (c) structure (mechanical design) of the third- and fourth-stage nozzle assemblies, and (d) liftoff seal design. Areas requiring resolution are; (a) second-stage nozzle design, (b) employment of redundant seals between each of the nozzles in the turbine, and (c) actuation medium for the face-seal liftoff bellows in the turbine alternator.

3. <u>Alternator</u>

a. Endurance test

The primary objective of the planned endurance testing is to operate the alternator and associated electrical control components until incipient failures can be detected or actual failure occurs. The goal will be to operate the alternator and associated electrical control components for 15,000 hours.

b. Endurance test facility

The alternator and electrical component tests are planned to be run in Building 194. The drive motor, gear box, and associated equipment are already available. The mechanical arrangement will utilize a turbine-bearing housing shaft and bearings as the connecting hardware between the alternator and drive motor and gear box. The heat sink for the voltage regulator and exciter, and the electrical controls and instrumentation are also available. Testing is planned to commence in March 1967.

The alternator to be used in the endurance testing was dismantled in order to obtain variables data. Subsequently, the unit was reassembled and installed in the test facility.

c. Fabrication and design

The alternator rotor from TAA 5/2 (S/N 481491) has been shipped to the vendor to be flame plated on the damaged surfaces. The damage was caused by screw-seal rubbing due to clearance reduction that resulted from loss of bearing preload (Ref. 4). This method has been employed so as to ensure availability of the alternator, since the lead time to machine a replacement is approximately 5 months.

B. MERCURY PUMP MOTOR ASSEMBLY (MPMA)

1. <u>Summary</u>

The development of the SNAP-8 MPMA has consisted primarily of the following activities; (a) Resolution of the motor cavity flooding problem (reported previously in Reference 4),(b) Initiating procurement from the original vendors of four spare motor units (Westinghouse) and 24 ball bearings (ITI), (c) Minor design improvements incorporated in detail drawings, (d) Completing design and initiating procurement of a prototype liftoff seal (this is described in more detail in the TAA Section), and (e) Assembly of MPMA 2/5 for endurance testing purposes in LML-5.

2. Motor Cavity Flooding

The investigation of this problem was completed and the findings, based on laboratory testing, indicated that the flooding was not due to faults in the MPMA. Complete details of the investigation are described in Reference 5. The conclusions indicate that a restriction or obstructions of the L/C discharge lines from the bearings to the degassing tank must have occurred. It was recommended that the following steps should be taken in order to reduce the probability of the recurrence of this problem.

a. Remove and cap-off the oil overflow line from the bearings. This change, along with reduced L/C flow requirements, also reduces the power losses by approximately 200 watts and increases the allowed back pressure from 6.4 psi to 10.2 psia before bearing area flooding can occur.

b. Change operating instructions to run the PMA with the motor cavity drain line closed. The drain line would be opened only to drain gross amounts of L/C fluid in the motor cavity. For more adequate drainage, the drain line size should be increased from 1/4 in. to not less than 1/2 in. to accommodate the viscous mix - 4P3E fluid.

3. Fabrication

PMA 2/5 has been assembled and delivered to the LML-5 mercury-pump test facility. This unit is to be tested for the purpose of evaluating endurance performance and space seal leakage. Additional information regarding the LML-5 is discussed in Section III-B.

C. NaK PUMP-MOTOR ASSEMBLY (NPMA)

1. Description of the NaK Pump-Motor Assembly

Two NaK pump-motor assemblies are required for the SNAP-8 system, one for the primary (reactor) loop and one for the heat rejection loop. Because of the similarity of the two-loop requirements, one model is used in both positions. The hermetically-sealed NaK pump-motor assembly incorporates on a single shaft a centrifugal pump, a hermetically-sealed motor rotor, and an internal lubricant-coolant circulating pump. The three-phase, 208 volt, 400 cycle, squirrel-cage, canned, induction drive motor is hermetically sealed from the coolant flow and NaK environment to preclude contamination by NaK of the magnetic and conductor materials. Inorganic (ceramic) insulation is used to provide maximum reliability in a radiation environment as well as permitting the motor to operate at winding temperatures up to 600°F for 10,000 hours. The rotor shaft is supported on two pivoted-pad, hydrodynamic, NaK-lubricated journal bearings. The shaft axial thrust loads are supported by a double-acting, pivoted-pad thrust bearing. The pump is separated from the motor structurally by three, pinned, load support arms and a small fluid-passage annulus. This design provides a thermal barrier which allows 1300°F NaK to be pumped while the motor temperature is maintained at an average of 375°F.

2. Development Testing and Analyses

a. NaK PMA 2/3 (P/N 093200-13) S/N A-1)

After completing 596 hours of operation in LNL-3 and accumulating 672 starts, S/N A-1 was removed from the loop on 22 September 1966, disassembled, and inspected. The inspection results which were expected to disclose only an impeller back vane-to-housing rub similar to what is shown in Figures II-3 and II-4, revealed a damaged stator and rotor can with severe circumferential marks in the area of the rotor ends. Corresponding rubs were found on the rotor in the area of the rotor resistance rings. Figures II-5 and II-6 show the location of these rubs. The severity of the rub on the rotor is shown in Figure II-7 where the can material has been completely rubbed through, allowing NaK to enter the rotor can cavity. The can was found to be deformed outward in these areas by .031 inches on the recirculation pump end and 0.015 inches on the main pump end.

The mechanism of failure was due to an overheating of the copper resistance rings within the rotor, causing them to expand outward beyond the OD of the rotor laminations. The expansion caused a permanent set in the Inconel rotor can greater than the rotor-stator gap. This overheating resulted from power repeatedly being applied to the motor during restarts without allowing sufficient time between power applications to dissipate the heat buildup. Power supplied to the motor while the rotor is locked results in heat being generated within the copper. Figure II-6 shows the effect of the expanded resistance rings on the rotor can.

Due to this failure, the start procedure has been modified to prevent recurrence of the overheating.

b. NaK PMA P/N 093200-13, S/N A-5 (3,028-hour unit)

As replacement for S/N A-1, this unit was installed in LNL-3 on 11 October 1966; S/N A-5 exhibited difficulties in establishing recirculation flow within the PMA. Investigation revealed severe plugging of the recirculation system had taken place. As a result, a section of line had to be removed in order to clear the plug. After the removed line was repaired, the PMA was started and recirculation flow was established. However, difficulty was encountered in restarting after the cold hydraulic performance tests were completed. The application of voltage resulted in loud noises coming from the NPMA similar to growling or grinding of mating surfaces. The noise level was observed to increase with increased voltage. The noise indicated rotation but the speed sensors did not confirm this observation. An electrical check of the power supply indicated that the motor was behaving normally. The difficulty in starting was overcome by applying high starting voltage. While operating at 400 cycles, the PMA ran normally without further sign of difficulties.

Normal operation of S/N A-5 continued through 7 November 1966 at which time, after 363 hours of unattended operation, a facility power failure caused the PMA to shut down. The PMA was restarted but exhibited the same type of noises that were noted previously. It was decided that continued PMA operation presented a major risk and that the loss of a valuable data point (3600 hours of operation) might be experienced. The PMA was removed from the loop on 18 November 1966.

The results of the inspection revealed that the recirculation pump-end journal bearing had failed. A severe machine action had taken place on both the journal and the pivoted pads, shown in Figures II-8 and II-9. The surface finish was approximately 200 microinches and all traces of the original bearing surfaces were removed. The main pump end journal bearing, Figures II-10 and II-11, although severely scratched and polished as the result of the debris running through the bearing, was still in an operable condition. The remaining PMA parts were examined and found to be free from damage.

The failure is attributed to the lack of a filter on the NaK refill system. As a result, the refill system was modified to incorporate a 5-micron filter.

NaK PMA S/N A-5 was reassembled with a new rotor shaft assembly and replacement pivoted journal pads while maintaining the original bearing pivots, balls, sockets, etc. The unit was reinstalled in LNL-3 for the continuation of the remaining hours of endurance testing.

c. NPMA 6/2 (P/N 093200-13, S/N A-7)

This unit was reinstalled in the primary loop of PCS-1, following its disassembly, inspection, and cleaning (covered previously in Reference 4). The unit has operated successfully for 304 hours and 72 starts at temperatures up to 1330°F.

d. NaK PMA 5/3 (P/N 093200-13, S/N A-6)

This unit successfully operated in the heat rejection loop of the PCS-1 Phase IV system for 186 hours and 109 starts. The first phase of a minimum voltage start test was conducted in PCS-1 Phase IV on the S/N A-6 and A-7 units. Results of these tests are shown in Figures II-12 and II-13. These results will be used as a basis for the change in starting voltage requirement as a function of time and operating temperature.

e. NaK PMA 10/1 (P/N 093200-13, S/N A-10)

The S/N A-10 unit has been acceptance tested in the NaK Simulation Loop (NSL) which uses water as the working fluid. These tests consisted of locked rotor, overall performance, motor pullout-torque determination test, and a rated-load heat run.

The results of the locked rotor or starting-torque test indicated that S/N A-10 is comparable to previous units, as indicated below (from a torque standpoint), although it did exhibit a faster heating of the winding during the test.

COMPARISON OF STARTING-TORQUE TESTS

	Unit 10/1	Unit 5/2	A-1 Original
At 400 cps Volts L-L	208	211	208
Ave. amps	48.8	51.6	51.2
Input kw	3.16	2.85	2.80
Torque in No.	19.2	18.8	17.4
At 60 cps Volts L-L	37.2	36.9	37
Ave. amps	41.5	48.5	48
Input kw	1.74	1.68	1.75
Torque in No.	64.0	61.4	59.5
At 95 cps Volts L-L	38.8	39.3	38.8
Ave. amps	28.5	33.1	33.8
Input kw	9.37	8.82	0.78
Torque in No.	18.4	17.4	17.8

The motor pullout torque was checked and found to be normal as follows:

	Unit 10/1	Unit 5/2	A-1 Original
Indicated input, kw	5.64	5.35	5.22
Capacity point, gpm	140.8	146.5	140.00
Head ft	74.7	67.8	75.0
Pullout volts L-N	114.0	111.5	114.0

The overall performance of NaK PMA 10/1 as shown on Figure II-14 is compared with previous tests and shows the power input to be 0.4 kw higher. As a result of indications of a much hotter motor temperature from previous tests, a rated load heat-stabilization test was performed. It was found that the motor hot spot temperature settles at 359°F above the cooling media temperature. This yields a 709°F winding temperature when operating in NaK.

The results of all tests performed on unit 10/1 (S/N A-10) indicate that the higher motor temperature is primarily due to poor heat transfer characteristics between the winding and the cooling medium. The condition is aggravated by approximately 400 watts of additional losses. It has been concluded that this unit may be used on an "emergency-use only" basis until a replacement unit is made available.

3. <u>Motor Insulation Development</u>

The motor insulation development program, instituted in September 1966, has been successfully completed. The primary achievement of this activity was an improved potting procedure which yields a high-density fill of the inorganic ceramic insulation used in the NaK PMA high-temperature motor. The second major accomplishment was the development of a motor-winding potting compound which is capable of completely encapsulating the individual strands of wire without the use of residual rock aggregate that in the past was found to be detrimental to the glass insulation of the stator wires.

D. LUBRICANT-COOLANT PUMP-MOTOR ASSEMBLY (L/C PMA)

The lubricant-coolant pump-motor assembly is required for the SNAP-8 fourth loop. Its function is to lubricate and cool a number of the SNAP-8 system components. The L/C PMA consists of a single shaft with a straddle-mounted motor rotor and an overhung single-stage impeller. The main support bearings and the thrust bearing are made of carbon graphite. The assembly is self cooled and lubricated by the organic fluid (mix-4P3E) which is bled from the pump discharge through the motor and returned to the impeller by means of a hollow shaft. The motor is a three-phase, 208 volt, 400 cycle squirrel-cage induction motor. The motor insulation system is an ML-film insulated wire construction which has a demonstrated compatibility with the mix-4P3E. Tests were performed with an ML-insulated winding operating at temperatures of 350°F without any signs of insulation degradation or deterioration through more than 20,000 hours.

The successful performance demonstrated by seven L/C PMAs indicates that this assembly will meet the needs of the SNAP-8 system. These units have accumulated a total operating time of 9,159 hours. Two of the seven units were operated during the report period.

L/C PMA S/N 481501, located in LNL-3, operated for 1260 hours with 316 starts during the report period. This assembly has accumulated a total operating time of 4,552 hours without any degradation of performance. L/C PMA S/N 481507 has operated in the PCS-1 Phase IV test facility from 10 July 1966 to 30 December 1966, accumulating 408 hours of operation with 74 starts.

E. HEAT EXCHANGERS

The major work in the development of heat exchanger components this quarter has been recovery from a boiler failure (reported in the last quarterly, see Ref. 4) which occurred in conjunction with PCS testing. After the failed unit had been evaluated, it was concluded that a materials change will be required for future units. Tantalum has been selected as the reference material and work has been initiated to obtain refractory metal boilers.

A refractory metal boiler development plan is being accomplished, utilizing laboratory scale, and subcomponent test, as well as analytical techniques that culminate in the design and fabrication of a full-scale refractory metal boiler.

1. Non-refractory Boiler

a. Boiler Description

The SNAP-8 tube-in-tube (T-T) boiler (P/N 097444-7, S/N A-1) shown in Figure II-15, is a counterflow heat exchanger where the entering subcooled mercury is preheated, evaporated, and superheated in a single pass. The mercury flows in seven 30-ft long tubes which are nested within an outer tube. The NaK counterflows in the area between the tubes containing mercury and the outer tube. The entire assembly is coiled to complete the configuration. A plug to restrict flow is placed in the inlet of each of the seven parallel flow passages, causing a liquid velocity up to 6.5 fps. The plug in this restricted flow section is a hollow rod spaced from the inside of the tube by either a spiral wire or by machined threads; the mercury flows in a spiral path in the annulus formed between the plug and tube. The pitch of the spiral varies with the boiler configuration. Downstream of the 5-ft long plug, the spiral flow is maintained by a spring insert that rests against the inside of the tube. The 0.060-in. diameter spring coiled on a 2.5-in. pitch, serves to separate the high density liquid from the vapor in the high quality region of the boiler.

b. Failure Analysis and Corrective Action

The failure of the T-T boiler (P/N 097444-7, S/N A-2) which had operated for a total of 587 hours in PCS-1 Phase IV has been evaluated to determine the failure mode and corrective action. The examination of the boiler revealed one primary and several secondary deficiencies which led to the failure. The metallurgical examination indicated additional areas, other than the failure that probably would have failed if operation had continued.

The primary failure was a leak in the mercury containment tube coupling the NaK and mercury flow circuits (Figure II-16). This failure occurred in the region of the tube-to-header joint at the mercury vapor outlet where the 321 SS spool piece is welded to the 347 SS header. Two additional tubes contained NaK-side defects similar to those existing in the failed tube although they had not propagated entirely through the wall. The primary cause of the failure was an overstress condition due to a bending moment at the boiler outlet, in conjunction with the presence of stress concentrations at the failure sites. Contributory causes to the failure may have been NaK corrosion, thermal fatigue, micro structural charge and a Nak-side hydraulic shock wave. Corrective action requires a reduction in bending moment at the joint and elimination of stress concentrations. This will be accomplished on existing and future units.

The bimetal tube joints (9M/321 SS) at the mercury outlet contained crack-type defects at the 9M side of the joints. These defects also had not propagated through the wall. Investigation revealed that the cracks in the 9M were the result of cyclic stresses produced by differential thermal expansion. Contributing to the cracking were the stress concentrations at the edge of the weld bead and the loss in strength of the 9M due to decarburization and increase in strength of the weld metal due to carburization. The deposition of corrosion products within the formed cracks may have contributed to crack propagation. The corrective action is to reduce the bending stresses, remove the weld bead and drop-through, and to invest the feasibility of a change in weld filler-rod. Also, the bimetal joints will be relocated to provide access for periodic inspection.

An examination of the mercury inlet end of the boiler revealed several defects which could have limited the life of the boiler if failure had not occurred at the outlet. These deficiencies included a local reduction in wall-thickness up to 0.051 in.; i.e., a wall thickness of 0.034 in. compared to the original thickness of 0.085 in. However, the analysis showed that some of this removal was probably produced mechanically prior to operation. A second defect noted was the extensive material loss from the hollow mild-steel plug inserts which included the entire loss of the swirl wire and severe wall thinning. Investigation failed to determine if the material loss was caused by corrosion or erosion. However, minimization of material loss in both tubes and plugs in subsequent boilers will be accomplished by employing a more corrosion resistant material such as tantalum.

The failure investigation showed that the gross failure in the boiler was probably preceded for a considerable time by an extremely small leak as shown by trace quantities of sodium and potassium observed in mercury dump-tank samples. Corrective action will include a more critical evaluation of the dump-tank fluid constituents; i.e., trace quantities of sodium and potassium in the mercury will be sufficient to initiate a search for the leak.

The conclusion reached is that the failed portion of the boiler can be corrected by relatively minor modification to the design. However, the excessive corrosion and/or erosion at the boiler inlet requires a change in mercury containment material. Tantalum has been selected as this new material and will be incorporated in the next generation of boilers.

c. Rework of Non-Refractory Boilers

A two-pronged approach has been taken to recover from the boiler failure. The first requirement was to provide a boiler rapidly for continued systems testing. The second requirement was to modify existing units to preclude a similar failure and extend the operational life of the present boilers until refractory metal boilers are available. Three boilers of the present configuration were available; two of the boilers (Units 1 and 2) had been tested previously, and the third boiler (Unit 3) was a spare. Unit 3 was selected for a minor rework which would permit continuation of systems testing and Units 1 and 2 were selected for modification.

The corrective actions resulting from the failure analysis (paragraph b) are summarized below:

(1) Lengthen the mercury outlet straight section. The additional length reduces the bending moment on the tube-to-header joint. This bending moment is the largest contributor to the stress at the joint. The new design point gives a reduction in moment from 600 in.-lb to 160 in.-lb.

(2) Thicken the mercury outlet header. This also reduces the bending moment on the tube-to-header joint. Increasing the thickness from the original design of 0.375 in. to 1.0 in. decreases the moment due to header deflection from 250 in.-lb to approximately 10 in.-lb.

(3) Remove stress concentrations on mercury containment tubing. The local increase in tube stress from stress concentrations has not been qualitatively determined. However, qualitative increases in stress from 200 to 1000% have been reported for sharp discontinuities. Undoubtedly, the boiler failure would not have occurred in the 587 hours of operation had these stress concentrations been avoided.

(4) Install a spacer at the tangent between the mercury outlet straight section and curved portion of the assembly (see Figure II-17) to limit the radial movement of the tube bundle relative to the shell. This modification can ideally eliminate the applied bending

moment at the tube-to-header joint; however, due to manufacturing tolerances, only a partial benefit will result.

(5) Relocate the bimetal (9M/321 SS) weld from the boiler interior to the exterior. This change will move the joint to a lower stress region where it will be accessible for periodic external inspection.

(6) Change material at the boiler inlet to one which is more resistant to attack by the mercury.

The minor rework of Unit 3 to provide limited-life service consists of corrective actions (3) and (4), above (Figure II-17). Also, the plug insert material has been changed from mild steel to tantalum.

All of the above corrective actions will ultimately be applied to Units 1 and 2 (Figure II-18). The mercury tube material at the boiler inlet will be changed to a Ta/9M bimetal with the tantalum exposed to the mercury. This is accomplished by vapor depositing tantalum on the 9M and will be applied to the first 5 ft of boiler tube; i.e., the straight section shown in Figure II-15. Modifications to the two boilers are under way to accept this change in front-end material. Straight sections of 0.090 in. thick 9M and 0.110 in. thick 9M are in process as backup to the vapor deposited tantalum front-end. These front-ends are interchangeable and can be replaced in the test facility. If production of the vapor deposited tubing is delayed because of the developmental state of the process, the alternate (backup) front-ends will be used but on a temporary basis only.

2. Refractory Metal Boilers

Two concepts for including refractory metals in the SNAP-8 boiler are being developed. The first of these is termed the bare refractory concept. This concept consists of a tantalum-mercury containment tube surrounded by a layer of stagnant fluid which, in turn, is contained by a stainless steel tube. The seven concentric tubes are attached to headers and are surrounded by a shell which contains the NaK. The purpose of the double containment is to protect the tantalum from impurities in the flowing NaK which would result in embrittlement. The second concept being developed is similar to the present non-refractory design except bimetal austenitic-tantalum tubing is used for mercury containment. The tantalum is exposed to the mercury and is protected from the impurities flowing in the NaK by the austenitic material. Tests and analyses are under way to support both design concepts.

a. Bare-refractory Boiler

This boiler concept is being developed by NASA LeRC with the supporting tests and thermal design being conducted by AGC. A preliminary analysis of the effects of double containment on boiler surface area has been completed.

(1) Double Containment Analysis

Double-containment mercury flow passages of variable-thickness static fluid layers were investigated to determine their effects on boiler design and performance. The analysis was based on the present T-T boiler (P/N 097444) plug insert design. The mercury tube internal diameter (0.652 in.), the number of mercury tubes (7), and the corresponding heat transfer parameters were used as a reference condition. The resultant heat transfer parameters were determined in non-dimensional form in terms of the stagnant liquid-metal layer thickness (t_{ST} = 0.010 in. to 1.000 in.), the stagnant layer composition, and the NaK-side heat transfer coefficient. The mercury side heat-transfer coefficients (h) were determined for the boiler preheat section and the plug-insert vapor quality region, using the SNAP-8 T-T boiler design heat-transfer correlations. The double-containment mercury flow passages require additional tube length as the stagnant liquid-metal layer thickness increases as shown in Figures II-19, II-20, II-21 and II-22.

Figure II-19 and II-20 show the relative increase in section length, using NaK as the stagnant fluid for the preheat and vapor-quality regions of the boiler, respectively. Also shown is the decreasing heat flux with static fluid thickness in the two sections considered. Figures II-21 and II-22 show the same information with sodium used as the stagnant fluid.

Each of the figures illustrate that the heat-transfer thermal resistance is a relatively weak function of the flowing NaK film coefficient. However, the required section length is strongly dependent on stagnant liquid-metal layer thickness. Consider, for example, a double containment geometry with a static NaK layer 0.2 in. thick. The preheat has increased length 1.93 times while the increase of the vapor-quality section is 1.80 times the present configuration. The plug insert for such a design would be approximately 9 ft long rather than 5 ft as in the current design. Were sodium used for the static layer, the plug length would be approximately 7 ft, reflecting the higher thermal conductivity of sodium.

A final design analysis is in progress which will consider the effects of double containment on the entire boiler, including effects of static layer eccentricity on heat transfer and pressure drop.

(2) Supporting Tests

The tests to support this design effort are covered in Section V-C, Seventh Scale Loop.

b. Bimetal Refractory Boiler

Work has begun on the prototype boiler specification (AGC-10621). This specification will provide a basis for future boiler designs independent of materials, internal configuration and containment requirements. An envelope control drawing (1264334) is in work for use in conjunction with the prototype boiler specification. These documents define the boiler requirements in detail and are compatible with the current PCS interfaces.

Effort has been started on the outside design and fabrication of prototypical refractory bimetallic boilers. Two boiler concepts are being examined which utilize bimetal boiler tubes for mercury containment. One concept terminates the bimetallic material at the mercury inlet and outlet headers while the alternate utilizes the bimetallic principle in the header region as well. Since these concepts require significantly different design approaches and fabrication techniques, they will be independently treated on separate contracts.

A survey was completed as an initial evaluation of outside suppliers having the background and/or potential capability to provide the design and fabrication support required for the prototype boiler concepts described above. Procurement activity will be initiated during the next report period to provide definitive conceptual designs for evaluation and eventual hardware procurement.

F. VALVES

1. Temperature Control Valve (TCV)

The function of the TCV is to control the heat rejection loop (HRL) and the auxiliary start loop (ASL) NaK flow during the system thermal start transient. A fixed amount of encapsulated NaK held in the body of the valve responds to variations of temperature from the ASL. Expansion of this NaK during heatup moves the main HRL flow shear-plate valve toward the open position, thus diverting the flow from the ASL to the main HRL. The valve is designed to start opening the HRL line at 500°F and to be completely open at a predetermined rate when the NaK temperature reaches 620°F. Compensation for over-temperature conditions up to 800°F also is built into the valve through a bellows-spring arrangement. The design operating pressure of the TCV is 40.5 psid.

Figure II-23 is a photograph of the TCV. HRL flow enters from the right and leaves from the left. The tube projecting outward from the center of the valve directs the flow to the ASL. The large appendage projecting upward contains the main flow shear plate, bellows, spring, shaft and pressure dome. The smaller diameter appendage projecting upward to the right of the main valve appendage contains the compensator bellows and springs. The very small tube projecting outward near the main flow inlet is the fill-and-seal port for the encapsulated NaK.

Figures II-24 and II-25 show the design performance curve and the calibrated performance curve for the two valves (S/N 100G and S/N 101G). At the present time, S/N 100G is on test in PCS-1 Phase IV and S/N 101G is at the W-1 facility of LeRC.

Evidence of binding was noted in the main valve of the S/N 100G TCV in November prior to the start of testing of PCS-1 Phase IV. Inspection of the spring, pressure dome and shaft of the main valve indicated that the spring was distorted and that there was some galling of the shaft in the bore of the pressure dome. The shaft was hand-worked to remove the gall marks and the pressure dome bore was polished and chamfered. The spring was replaced with a new design having ground ends, more turns and a lower operating stress level. The original spring had a total of 6 coils; 4 active coils, 0.093-in. Inconel X wire, and a stress level of 85,000 psi. The new spring has a total of 14 coils; 12 active coils, 0.125-in. Inconel X wire, and a stress level of 57,000 psi.

Testing of the refurbished S/N 100G TCV was continued in PCS-1 Phase IV in December 1966. Difficulty in controlling heat losses in the HRL during the test resulted in obtaining only a partial performance envelope. The maximum temperature of the main flow was 568°F. The following conditions were noted from a review of the raw data and by actual observations during the test:

a. The valve commenced to open at 507°F.

b. The compensator bellows shaft moved when the main valve bellows was not moving. This indicates that the encapsulated NaK expansion was exerting a motivating force to the compensator bellows rather than the main valve bellows at a time when the compensator mechanism should not move. This can occur as a result of too high a resistance to motion of the main valve shear plate and/or too low a resistive force of the compensator springs. HRL pressure was approximately 80 psia during the test. When the loop pressure was decreased to 43 psia in one case and 50 psia in a second case, and the loop temperature was decreased to 200°F, the valve closed.

c. Because of the problem in obtaining the desired temperatures rise in the HRL, the full traverse of the TCV was not realized.

d. The differential pressure from the TCV inlet to the auxiliary loop bypass line was 11.9 psi (77.5 psia in, 65.6 psia out) at 212°F and a bypass flow of 7738 lb/hr. The main valve was closed at this time with a differential pressure of 55.8 psi across it. A second data point taken indicated a bypass differential pressure of 11.0 psi (74.4 psia in, 63.4 psia out) at 566°F and a bypass flow of 7868 lb/hr. The main valve was partially open at this time with a differential pressure of 51.2 psi across it.

The conclusions reached based on the above observations and raw data are:

a. The TCV should function in an acceptable manner if the pressure in the HRL does not exceed the design criteria.

b. Adjustment of the compensator mechanism may be required to meet the valve start-transient performance envelope.

2. Double-Solenoid Latching Valves

The double-solenoid latch valves are used as general-purpose valves in the SNAP-8 system. Specific applications are the TAA and MPMA lubrication system valves, the MIS startup and shutoff valve, and the HRL auxiliary heat exchanger isolation valve. The valve consists of an opening and a closing solenoid which actuate a shear plate that exposes a venturi flow section. Latching for each motion is accomplished by spring-loaded balls moving into a detent. A photograph of the valve is shown in Figure II-26.

An order for six high-temperature (600°F rating) valves of the V-54600-16 configuration was placed in August 1966. A December delivery slipped to an expected delivery in February 1967. Procurement delays of electrical connectors and nickel-clad solenoid wire caused the slips. The substitution of Elgiloy for Inconel X spring wire for the current type 304 SS in the detents also was made in this period. Calculations and materials studies indicated that the type 304 SS springs would relax after exposure to temperature for long periods of time (approximately 100 hours).

A V-54600-06 600°F interim valve was removed from the ASL of PCS-1 Phase IV when it became evident that a NaK oxide plug in the valve prevented auxiliary loop flow during the start of testing in December 1966. This valve was flushed with Dowanol, electrically actuated and found to be fully operational. The difficulty was attributed to the presence of excess impurities in the ASL piping.

G. STARTUP SYSTEM

1. Mercury Injection System (MIS)

The original single-start MIS is currently being redesigned to reflect a restart and shutdown capability that will meet the latest system requirements.

The single-start MIS (P/N 094583-1) S/N A-1 was returned from the W-1 facility at LeRC for installation of a NASA-supplied pressure gage. A functional check of the assembly revealed two problems; i.e., a bellows leak and a sticking safety valve.

The MIS originally was shipped to LeRC on 29 November 1965 pressurized to hold the bellows in the nested position. This was done to minimize vibrational and shock loads on the bellows. However, it was reported that the unit was not pressurized when it was received at W-1. The unit was returned to Von Karman Center for the pressure gage installation and to reverse the installation of the double solenoid on 11 October 1966. The bellows was not pressurized during this shipment either. Inspection of the bellows revealed that one diaphragm was cracked and another diaphragm had a pinhole leak. It appears that several phenomena brought about this failure; the excessive vibration and shock loads experienced in transit, and the presence of pitting and rusting of the bellows. Both problems have been resolved and are noted in Remedial Action Progress Record, FR 0228.

The sticking safety valve was found to have a bent body, causing the valve to "hang up." This valve was installed as a safety feature after completion of the MIS, its purpose being to trap some mercury in the MIS near the end of mercury injection so that the bellows will not be subjected to an excessive differential pressure if a system malfunction occurs. To preclude leakage around the valve body, a 0.0005 to 0.0010-in. press fit was required. Also, the valve body had to be welded to the MIS after installation. It was concluded that these two conditions resulted in the distortion of the valve. To avoid this problem, the MIS and the double-solenoid latching valve will be assembled in the test loop so that inspection for distortion and misalignment can be made after each installation step.

As a result of the problems encountered above and the long period required to repair this unit, it was decided to reverse the installation of the double-latching valve and incorporate a pressure gage on MIS (P/N 094583-1) S/N A-2 which had been designated as a spare unit previously. It is expected that this unit will be shipped to LeRC by the end of January 1967.

The single-start MIS (P/N 094583-1) S/N A-3 is currently available for test in PCS-1 Phase IV.

2. Mercury Flow Control Valve

The mercury flow-control valve (P/N 097330-5) is a motor-operated, bellows-sealed valve utilizing a shear plate valve sliding across a shaped orifice. The speed of the valve and the shaped orifice define the flow ramp required for startup. Figure II-27 is a photograph of the valve and Figure II-28 shows its flow characteristics. S/N A-2 and A-3 have a motor-to-valve gear train modification to double the valve speed as requested for systems operation. In a parallel effort, three motors were ordered which operate at double the speed of the current motor. These were received in December 1966 and are currently in Stores.

S/N A-2 flow-control valve is available for PCS-1 Phase IV. S/N A-3 valve was returned from the vendor (Valcor Engineering Corp.) after repair of a bent actuation shaft, functionally checked, and sent to Stores.

3. Isolation Valve

The isolation valve (P/N 094587-1) is a spring-loaded check-valve designed to check mercury flow into the discharge of the mercury PMA during the mercury injection phase at startup. S/N A-3 has been returned to Von Karman Center for a functional test to determine valve leakage at various back pressures and also the valve cracking pressure. A photograph of the isolation valve is shown in Figure II-29.

4. Programmer

The function of the programmer is to provide the sequence of operation of valves, switches, MIS inverter, etc., required during startup, shutdown and restart of the SNAP-8 PCS.

Preliminary design requirements for the programmer that are needed in conjunction with restart capability have been generated and the initial design of the logic circuitry was started.

The type of components most suitable for the programmer application has been considered. It has been decided that relays will continue to be used for the switching functions instead of solid state devices because of the vulnerability of high-current silicon switching components to radiation damage and because of the favorable performance previously experienced with relays.

5. Inverter

The SNAP-8 inverter is used to supply power to the system pump motors during system startup and shutdown. The inverter requirements have been modified to reflect the system restart capability and the increased power required to start and operate the pump motors.

A study was made to determine if one or more of the present inverters (P/N 976J412-1) could be used to start the SNAP-8 System. Consequently, three inverter systems of the present design were tested as follows:

a. One inverter operated from an adjustable voltage dc source with an operating range of 7.5 to 60 volts. The speed of the inverter was adjusted by adjusting the dc input voltage. The higher input voltage increased the inverter motor capability.

b. Two inverters were operated in parallel from an adjustable voltage dc source with an operating range of 7.5 to 60 volts dc. The inverter outputs were connected in parallel while operating at minimum speed, prior to being connected to the pump motors.

c. Two independent inverters were operated from a 30-volt dc source. A switch was provided to reduce the supply voltage to 7.5 volts dc for operation at 25 cps. The pump motor loads were divided between the two inverters.

The following table compares the capability of the inverters with the system requirements.

	System Requirement	A	B	C
kva				
At 220 cps	7.0 kva	5.95 kva	7.0 kva	7.0 kva
At 95 cps	0.63 kva	0.63 kva	0.63 kva	0.63 kva
At 25 cps	0.17 kva	0.17 kva	0.17 kva	0.17 kva
Pump Motor Starting Torque	*65 in.-lb	18 in.-lb	27.5 in.-lb	18.5 in.-lb

*Based on a maximum test value of 49 in.-lb.

It was concluded that the present inverter has inadequate capacity to provide the required pump-motor starting torque.

An additional study was undertaken to compare the capabilities of static and rotary inverters to meet the SNAP-8 system startup and shutdown requirements. The results of the study indicate that either a static or rotary inverter could be developed to meet the requirements of the SNAP-8 system. Some of the comparative features of the inverters are as follows:

a. Efficiency - The efficiencies of the static and rotary inverters while operating over the SNAP-8 system duty cycle are comparable. The efficiency of the static inverter at full voltage is high. However, at the low voltage operating conditions required by the pump motors, the efficiency is low due to the semiconductor voltage drops in series with the motor windings. The increased motor losses due to the square voltage wave is charged against the inverter efficiency.

b. Cooling - Cooling of the static inverter components is a critical design consideration. Silicon-controlled rectifiers are derated to zero at 150°C (302°F), limiting the maximum coolant temperature to the inverter. The rotary inverter will operate at temperatures up to 220°C (428°F).

c. Nuclear Radiation - The semiconductors of the static inverter are generally less radiation resistant than the components of the rotary inverter.

d. Life and Reliability - There is a trade-off between the large number of components of the static inverter versus the critical components of the rotary inverter such as brushes and bearings. Applications involving low to moderate total operating life would tend to favor the rotary unit, whereas long operating life requirements would favor the static inverter. However, a final selection of the type of inverter to be used has not been completed.

H. ELECTRICAL COMPONENTS

1. Parasitic Load Resistor (PLR)

The function of the PLR is to dissipate the surplus power available from the TAA in order to hold the TAA output frequency at 400 cps $\pm$ 1%.

The basic design of the PLR has proven satisfactory, and it is not expected that there will be any change in this design. However, in order to provide a means for making a sealed electrical connection to the resistance elements of the PLR, a sealed housing will be provided to cover the terminals of the PLR. The concept of this design has been established and the drawings were being completed at the close of this report period.

2. Low-Temperature Controls Assembly (LCA)

The LCA is to be a sealed housing containing several of the SNAP-8 electrical control devices. The present concept is that it will contain the speed control module (SCM), the voltage regulator module (VRM), the power factor correction assembly, and the battery charger. Also, the present concept is that this package will be cooled with a liquid at a maximum temperature of 140°F.

An analysis has been conducted to determine if this package could be operated at a temperature higher than 140°F. It was established that both the SCM and the VRM can be operated on a heat sink at a temperature as high as 220°F. However, in order to maintain high reliability, the design of the SCM would have to be changed to relocate some of the components on the heat sink, and the capacitors in the frequency sensing circuit would have to be connected in a series-parallel configuration.

Neither the battery charger nor the protective system have been designed. However, they can be designed to use components similar to those in the speed control and voltage regulator, so that the complete LCA could be operated at a heat-sink temperature of 220°F.

An investigation of the speed-control frequency sensing circuit was concluded. This investigation was started to determine if this sensing circuit could be modified to eliminate the need for a bias that is now required during startup. Three circuit modifications were analyzed and laboratory tests were conducted. It was established that only one of the circuits would be suitable for use in the SNAP-8 system, and additional work must be done to produce fully satisfactory circuitry to replace the present stagger-tuned sensing circuit. The results of this study and analysis has been published in Reference 6.

3. Transformer Reactor Assembly (TRA)

The TRA is to be a sealed housing containing the static exciter module, the saturable reactor, the speed-control transformer, the vehicle load breaker and the motor transfer contactors. It will be cooled with a liquid coolant at 210°F, maximum.

The existing design of this package, which was completed during an earlier phase of the SNAP-8 program, is being reviewed and modified to accommodate additional components and to facilitate fabrication.

4. Electrical Harness

The electrical wiring, cabling, insulation, terminals, terminations and the mechanical and environmental protection of these components make up the harness for the SNAP-8 PCS.

During this quarter, it was recommended that the electrical circuits between components should be protected by flexible stainless-steel conduit and that the harness system should be sealed to give maximum protection to the wiring, insulation and terminals both on the ground and in space. A specification for this type wiring system is in process.

5. Power Factor Correction Capacitor Assembly

It is the function of this assembly to provide compensation for the lagging power factor load caused by the system auxiliaries and the vehicle load. As the alternator power factor is corrected toward unity power factor, its kva load is reduced and its efficiency is raised, making more power available to the useful load.

A value of 58 kva has been selected for the capacitor assembly rating which will correct the alternator power factor to unity with a full vehicle load of 35 kw at a 0.85 lagging power factor. The power factor correction assembly conceptually is considered to be made up of 30 individually sealed units rated 17.5 mfd at 208 volts (1.9 kva). This value was selected as a basic building block to allow reasonably sized incremental steps in the event of changing system requirements.

The effect of an individual capacitor failure within the assembly is of a small enough magnitude to minimize the effect upon the system performance.

Of the various types of capacitors available, polycarbonate film has been selected as possessing the best combination of desirable characteristics; e.g., low loss, a good operating temperature characteristic, and reasonable size. A procurement specification is being prepared to cover the requirements of the individual capacitors.

6. Vehicle Load Breaker (VLB) and Transfer Contactor (TC)

The VLB connects and disconnects the vehicle load and the SNAP-8 PCS. The TC transfers the NaK PMA's and the L/C PMA from inverter supply to alternator supply during the startup operation.

The specifications for these items were completed and requests for quote were sent to five possible vendors. Only one vendor quoted. The others declined to bid because of the large amount of work they have and because these devices require development work and there is little hope of substantial volume.

7. Battery Assembly

The battery assembly will supply all the power required during startup and restart of the SNAP-8 EGS, and it will also be required to supply the power needed during controlled shutdown.

A preliminary estimate of battery requirements was completed and then discussed with several vendors to obtain their comments and recommendations.

A recommendation that a silver-cadmium cell with inorganic separators be developed for this application was received. Other vendors also have indicated interest in supplying the battery cells required. However, it has been decided that work on the battery assembly will be curtailed until the battery requirements are better known.

I. INSTRUMENTATION AND DATA REDUCTION

1. Data Processing Improvement

Work was initiated to automate the transducer calibration evaluation which is presently done by hand plots.

The instrumentation sensitivity and zero analysis routine was made operational and will become a part of the daily routine for PCS-1 data evaluation.

III. MINOR COMPONENT TEST LOOPS

A. LNL-3

At the start of this report period a NaK PMA changeover from S/N A-1 to the 3,000-hour unit, S/N A-5, was in progress. Analog and digital level probes of the "I" type were installed in the NaK expansion tank. A new vent valve was installed between the expansion tank and the dump tank in place of one which had become stuck in a closed position. Approximately 85 lb of NaK were added at the dump tank to make up for losses incurred during the pump changeover. The loop was leak checked with a mass spectrometer when assembly work was completed, and found to be leak tight. Difficulties were experienced with S/N A-5 subsequent to completing the loop repairs. These difficulties are described in Section II C.

After the problems encountered in S/N A-5 (i.e., the recirculating loop was unplugged) were corrected, an endurance run was started on 24 October 1966. Some difficulties were experienced with loop heaters due to shorting to surrounding metal but these were quickly rectified. The loop temperature was raised to 1170°F (nominal) and was maintained with a power input of approximately 6.5 kw.

On 7 November 1966, after 339.3 hours of hot running, what is believed to be a lightning-induced power failure shut the loop down. The NPMA was restarted on 70 volts and 60 cycles. It was then switched to 400-cycle operation. Loop heaters were again energized and the loop was brought to the 1170°F operating temperature.

The loop continued to operate normally with S/N A-5 until it was shut down when power to the control panel was inadvertently interrupted. Restart attempts using up to 75 volts and 60 cycles failed. Loud growling noises were heard during these attempts and the decision was made to remove the pump to investigate the cause of the noises.

NPMA Elapsed Endurance Run Time: 571.7 hours*

L/C PMA Total Time (This buildup) 1257.9 hours

*Total Time this Buildup: 580.6 hours

S/N A-5 was removed from the loop on 18 November 1966 and inspected and repaired as described in Section II C.

During this down period, the heaters also were inspected and repaired. Their problems stemmed primarily from poorly supported connections. Reinforced leads were installed and held in place with refractory cements. Electrical instruments were sent to the Standards Lab for calibration. Temperature recorders were calibrated in place.

S/N A-5 was returned to LNL-3 after rebuilding on 21 December 1966. The pump was rewelded into the loop on 28 December 1966 and mass spectrometer leak checks indicated that there were no detectable leaks. Remaining installation items are in progress.

B. LIQUID MERCURY LOOP-5 (LML-5) - MPMA TEST FACILITY

LML-5 was added to the SNAP-8 program and is the outgrowth of an existing loop, LML-3, in Cell 3 of Building 180.

The existing loop in Cell 3 was originally designed for remote operation from the Building 180 control room. During rewiring of the building all power, control, and instrument wiring to the existing LML-3 had been disrupted. This, combined with the fact that considerable mechanical equipment had been removed from the loop, resulted in the decision to build a new loop utilizing the available equipment from the old loop.

Design effort commenced early in November. The piping and instrumentation diagram (Figure III-1) is based on a capability to accomplish all objectives of the MPMA test plan indicated in Section II-B. The first loop configuration to be built is called Phase 1 (Figure III-2) and allows for performance testing and gross space-seal leakage measurements of the MPMA. Subsequent buildups will allow the space simulating vacuum and leakage collection system, start programmer, and possibly other SNAP-8 components to be installed so that the loop will be ready for Phase II testing.

IV. PCS-1 PHASE IV

PCS-1 Phase IV is a full-scale SNAP-8 engine facility arranged in a breadboard configuration. Except for the expansion reservoirs, this configuration contains all of the PCS components and the necessary TSE to simulate complete SNAP-8 engine operation.

Testing of this facility to determine component and system performance (Step 3) continues. Following a boiler leak (reported last Quarterly period) which had allowed cross leakage of primary and secondary fluids (NaK and mercury), a large portion of this system and its components were removed for decontamination and/or evaluation. During this quarter all loops, with the exception of the mercury loop, were put in operational condition with a spool piece used to simulate the boiler in the primary loop. Testing was conducted on the NaK and L/C components and the electrical controls. The mercury loop will be completed, following boiler availability and full system startup tests that are scheduled to be conducted during the next quarter.

A. DEVELOPMENT ENGINEERING

1. Mechanical Design and Fabrication

Decontamination of the primary NaK loop continued with two additional 1300°F NaK flushes which brought the total number of flushes to four. The last flush (fourth loading) brought the loop contaminant level down to <1 ppm of mercury. Due to the low (acceptable) contaminant level of this last load, it was retained in an auxiliary dump tank for operational use after chemically cleaning the main dump tank. Prior to the last flush, a major PNL line configuration change was accomplished. This included a complete rerun of the NaK gas-fired heater inlet lines and relocation of the NaK/NaK heat exchanger and the PLR from the loop. The purpose of this change was fourfold: (1) to remove low points of the loop and components and separately decontaminate prior to the final flush, (2) rearrange plumbing to allow complete loop draining (except for the NaK PMA), (3) to allow installation of the NaK/NaK heat exchanger and PLR in their latest PCS reference position (NaK/NaK heat exchanger immediately downstream of the boiler and the PLR downstream of the condenser), and (4) to reduce the ΔP of the primary loop from 19 to 17 psi at 50,000 lb/hr.

The common NaK purification system was completely redesigned into two systems capable of individually purifying both the primary and heat rejection loops. The two systems were installed and made operational.

The study of a method for detection of mercury leakage into the NaK loops by using Hg^{203} was terminated. It was decided that the new analog probes in the mercury dump tank and a valve leakage detector in the emergency mercury dump line would give operating personnel sufficient control of mercury inventory to enable them to limit any future cross leakage.

In the latter part of the quarter it was decided to terminate all design and fabrication of the space-seal leakage detection system. The PCS-1, as currently installed, has the capability of determining gross leakage from the TAA and MPMA as a function of time. However, it does not have the capability during a run to the measure the small amount of leakage into the space-seal cavity. These measurements will be obtained during operation of LML-5 and the seal leakage rig.

Mercury loop reconstruction after its decontamination was deferred until the W-1 boiler would be available for installation. In the interim, the primary, heat rejection, and lubricant/coolant loops were placed in operational condition to run NaK PMA, inverter, programmer, and Auxiliary Start Loop (ASL) tests. Prior to these tests, the following components were installed: TAA 1/4, PNPMA, MPMA, PLR, NaK/NaK heat exchanger, and the TCV.

2. Instrumentation

During this report period, all instrumentation required to run the NPMA's, inverter, and ASL heat exchanger was placed into operation.

Fabrication was completed on the new mercury vapor venturi and the unit was shipped to the Colorado Engineering Experiment Station for special calibration.

All fabrication was completed on the new mercury analog level probe systems. When loop modifications are complete, final checkout on this system will be performed.

All design and procurement on the space-seal leakage detection system was completed. Approximately 50% of the fabrication effort was completed before work was stopped.

3. Electrical Controls

The electrical controls for the Step 3 startup in December 1966 operated satisfactorily and no problems were encountered.

The temporary installation of the SVM-2 (solenoid valve monitor--2 valve) into the control console was completed and successfully checked out. The SVM-6 and the checkout unit for both solenoid valve monitors were completed. The SVM-6 is awaiting installation.

The space-seal leakage detection system heater control fabrication is complete.

A duplicate purification system heater control was designed and installed. The system was used during the December 1966 tests.

A mercury monitor redesign employing total use of solid state components was continued. The schematic, wiring diagram, and assembly drawings are approximately 85% complete and procurement is approximately 80% complete.

4. Future Operations

The next loop operations will include all components required for complete startup tests. The MIS, isolation valve, and the flow-control valve will be reinstalled and on-line calibration capability provided for three of the primary mercury loop functions (boiler in-pressure, turbine in-pressure, and vapor flow). The double latching solenoid valve position indicators also will be installed. The W-1 boiler (Unit 3) with tantalum plugs will be installed for these startup tests.

Shakedown of the system and initiation of startup tests is scheduled for early February 1967. The termination of the startup tests will be dictated by either the completion of 20 starts or 250 hours of mercury-side boiler operation. An inspection of the boiler will be conducted at this point to determine the feasibility of continuing with this boiler.

Following startup tests, the present scheduling effort shows replacement of the boiler with Unit 2 (replaceable plug section) and installation of TAA 5/3, followed by a 2500-hour endurance run.

B. SYSTEM PERFORMANCE

During this reporting period, the data accumulation and presentation capability has been upgraded. The data presentation now includes SEDAN (performance data calculation), graphic presentation (plots) utilizing the Cal-Comp Plotter, and ADP-3 recorded test data that includes a loop schematic routine.

1. Auxiliary Start Loop (ASL) Tests

The ASL heat exchanger was first tested in RPL-2 in February 1965. During these tests, the overall conductance of the heat exchanger was found to be 425 Btu/hr-$^{\circ}$F, which is about twice the expected value.

In order to meet the PCS startup requirements (70 kw heat transfer and a radiator inlet temperature less than 650°F), a bypass-orifice arrangement has been added to the heat exchanger. An orifice also has been placed in line with the heat exchanger to increase the pressure drop for better flow control.

The purpose of the testing was to evaluate the ASL performance in light of PCS requirements. The specific objectives of the test program were:

a. Confirm or revise the value of overall conductance found in RPL-2 testing of February 1965.

b. Evaluate the flow division and control achieved with the in-line and bypass orifices.

c. Determine the performance of the ASL during conditions simulating PCS shutdowns and PCS reactor decay periods.

The overall conductance was found to be 411 Btu/hr-$^{\circ}$F with a standard deviation of ± 14 Btu/hr-$^{\circ}$F. The conductance coincides well with the value of 425 Btu/hr-$^{\circ}$F found in RPL-2. This confirmation is valuable since it makes the present bypass flow arrangement applicable to PCS.

Based upon the conductance determined in the RPL-2 tests, the design value of bypass flow was 67%. The testing indicated that the bypass flow was 67.7% with a standard deviation of ± 0.032%.

With the heat exchanger overall conductance known, it was possible to predict PCS ASL conditions. Figures IV-1,- 2 and - 3 show the PCS operating points for the startup and prestart phases of the system startup sequence. The curves shown are based upon (1) a primary-side inlet temperature of 1300°F, (2) an auxiliary side inlet temperature of 100°F, and (3) a startup-phase primary flow rate of 24,500 lb/hr (220 cps pump operation). Figure IV-1 presents heat rejection rate vs auxiliary loop flow. It is seen that the required auxiliary flow rate to transfer 70 kw during the startup phase is 3650 lb/hr. The ratio of primary flow rate to auxiliary flow rate thus established (24,500/3650 = 6.7) becomes a constant which is maintained at all auxiliary loop flow rates (i.e., as pump speed changes).

With the ratio of primary to auxiliary flow specified, the radiator inlet temperature and heat exchanger auxiliary side outlet temperatures are as given in Figure IV-2 and IV-3, respectively. It will be noted that the heat transfer requirement (70 kw) is met with the radiator inlet temperature remaining well below the system operating limitation (650°F).

The heat exchanger testing to evaluate performance during PCS reactor decay periods is inconclusive. The purpose of the testing was to determine if the heat exchanger overall conductance changed at the low flow rates of this phase of operation. It was found impossible to accurately measure the flow rates since the flow rates were only about 10% of the values for which the instrumentation was designed.

The design values were based upon obtaining accurate data at the flow rates involved in PCS startups. However, it can be assumed that the conductance of 411 Btu/hr-^{o}F found for the startup case also applies for the reactor decay period. This conclusion is based upon theoretical analyses which indicate that the controlling thermal resistance in the heat exchanger is the stagnant NaK layer separating the primary and auxiliary sides. This thermal resistance is not a function of flow rates and, consequently, flow rates should have little effect on the heat exchanger overall conductance.

The tests to determine the heat exchanger performance during a PCS shutdown were only partially successful. The objective to determine the heat exchanger overall conductance was successful with confirmation of the previously determined conductance (411 Btu/hr-^{o}F) being achieved. However, attempts to evaluate the heat exchanger at higher auxiliary-side inlet temperatures, as would occur in a shutdown, were basically unsuccessful. The problems were (1) a lack of heat input to raise and control the temperature (because of the absence of the mercury loop heat input) and (2) transient temperature effects due to changes in heat losses as the temperature reached the point that the HRL TCV opened and allowed flow in the main line of the HRL.

2. Inverter-PMA Start Tests

The purposes of these tests were to investigate the capability of the inverter to start the PMA's according to the prescribed PCS start sequence and to accelerate the PMA's simultaneously from 95 cps to 220 cps. In every case, successful starts were made. The sequence of starts was as follows: (a) The HRPMA was started alone, (b) With the L/C PMA running, the HRPMA was started, (c) The L/C PMA and HRPMA were started simultaneously, and (d) With the L/C PMA and HRPMA running, the PNPMA was started.

The above sequence was successfully conducted both with and without the use of a capacitor connected to the inverter output terminals. However, the capacitor will be used in the forthcoming PCS startups since future starts may experience increased PMA torques (as has been found in past tests); the inverter may require the added capability resulting from the capacitor.

Following the startups, the capability of the inverter to accelerate all the PMA's from 95 cps to 220 cps was tested. Before proceeding through the acceleration ramp, the inverter input dc voltage was raised from 28 to 37 volts. The voltage increase was made to prevent an excessive inverter input current at the higher frequency operation. The current was about 135 amp at 220 cps and 145 amp at 235 cps. It is expected that during a PCS startup with the primary loop at temperature, the current at 220 cps will be about 125 amp, which is the recommended limit.

A problem found during the acceleration ramp was a speed instability which occurred at speeds between 165 and 195 cps. The same problem was experienced in laboratory tests of the inverter. To correct the problem, a stabilizing network was put in the start programmer. The stabilizing network successfully corrected the instability in the laboratory test but did not correct the instability in the Step 3 testing. The difference in performance may be due to the fact that the laboratory tests simulated the pump-motors with static loads and, consequently, did not account for dynamic loads, or the difference in performance may have been caused by the load the PMA requires from the inverter that is higher than the designed load. The instability has no effect on the forthcoming PCS-1 Phase IV Step 3 system startup tests since the testing incorporates the startup sequence after the PMA's are at 220 cps which is a stable operating point. A change of inverter was required during the tests due to an accidental partial demagnetization of the inverter which was caused by a short circuit in the capacitor assembly. Prior to removal, it was determined that the partially demagnetized inverter was still capable of accelerating the pumps.

3. Start Programmer

The start programmer was tested for the first time in a system. The following significant features were found:

a. The programmer accurately timed and initiated the PMA startups.

b. The programmer successfully switched between the inverter high- and low-voltage windings.

c. The programmer properly initiated and operated the acceleration ramp. (As noted above, an inverter speed instability problem occurred).

d. The programmer was adjusted to set the inverter upper frequency at 220 cps.

4. NaK PMA Performance Tests

The primary and heat rejection loop NaK PMA's were tested to determine the minimum voltage requirements for starting (60 cps). The tests provided a basis for comparison to see the magnitude of starting torque changes with time for each PMA. The initial tests will be repeated periodically during Step 3 testing. Also, the NPMA's were tested to determine their head vs capacity performance. Analysis of the data is not completed on the PMA's. More detail on performance will be published at a later date.

5. Heat Rejection Loop Temperature Control Valve

The HRL temperature control valve was tested to verify its setpoint and to determine its flow vs ΔP as a function of valve position. The following significant features were found:

a. The valve setpoint is between 505 and 515°F.

b. The valve movement is sensitive to the loop operating pressure. That is, the valve appeared to stick; its frictional resistance is a function of the operating pressure.

c. A correction to the valve performance is necessary before reference system startup sequences can be demonstrated in PCS-1 Phase IV. The present operation of the TCV would result in a condenser overpressure before the startup sequences were completed.

In summary, the PCS-1 Phase IV Step 3 testing conducted during 19 to 29 December 1966 was valuable. Good information was gathered on inverter-PMA start characteristics, heat exchanger performance, and NPMA starting torque requirements. In addition, problem areas requiring further design and/or testing were identified concerning inverter-PMA speed instability and the HRL TCV.

V. TECHNICAL SUPPORT

A. SYSTEM ENGINEERING

1. PCS Analysis

a. Restart Concept Study and Analysis

The restart concept advanced in the previous quarterly report is shown in Figure V-1. The concept was synthesized to meet the recently added requirement that the SNAP-8 EGS be capable of repeated starts and shutdowns. While much remains to be investigated before a final operational procedure can be adopted, a reference approach to the system operational sequence of startup and shutdown has been analyzed and is shown graphically in Figures V-2 and V-3.

(1) Conditions Prior to Startup

Prior to startup of the EGS, the following conditions are assumed to have been established:

(a) PNL and HRL filled with proper inventories.

(b) L/C loop filled with proper inventory except for TAA and MPMA bearing and space-seal regions.

(c) PNL and HRL maintained at temperature sufficient to prevent local freezing which would prevent fluid circulation.

(d) L/C loop and fluid preheated at temperature sufficient to permit fluid circulation.

(e) Mercury loop, alternator cavity, MPMA cavity, MPMA and TAA bearing and space-seal cavities evacuated.

(2) PCS Mercury Reservoir Operational Requirements

To be compatible with the requirements of the PCS, the mercury supply system must have the following operational capabilities:

(a) It shall be capable of supplying mercury to the system for repeated startups. The number of startups has not been defined precisely; however, it is expected that provision for 20 startups should be considered with the possibility that as many as 100 startups may be required during ground testing.

(b) It shall be capable of operating satisfactorily under gravity conditions ranging from 0 to 1 g. When operating in a gravity field, the gravity vector shall be from the PCS toward the reactor.

(c) It shall be capable of receiving mercury at temperatures varying from 100 to 500°F from the system and operating within specified conditions.

(d) It shall be capable of being recharged under both normal shutdown and emergency shutdown conditions.

(e) It shall be capable of maintaining continuous control of the system inventory within ±5 lb.

(3) Mercury Reservoir Operational Requirements

The reservoir shown in Figure V-1 constitutes the reference concept which renders the PCS restartable. The reservoir utilizes the MPMA discharge pressure to maintain the proper outlet pressure during system operation. The injection valve is open during injection and for a short period during system operation but closed during the pump-down or recharge operation. The recharge valve is kept closed throughout startup and system operation and is opened during pump-down for approximately two minutes.

The mercury reservoir, which includes all cavities within it, must have a capacity of at least 400 lb of mercury. This value accounts for the design operating inventory requirement for the PCS, the additional mercury requirements during startup necessitated by a deconditioned boiler, condensation in the TAA line, and extra condenser inventory during certain phases of startup. The 400-lb requirement also includes a 40-lb mercury loss through the space seals for all operating and nonoperating conditions as well as a 36 lb nonexpulsable quantity for the reservoir.

The reservoir operational requirements have been defined and based upon three operating conditions; (1) prior to startup, (2) when the TAA reaches 220 cps, and (3) at the design operating point. Three conditions were required to completely define the relationship between the amount of mercury in the reservoir and the high and low pressures across it. The first condition is that prior to startup, and when the MPMA is not operating, the pressures at the high pressure (p_{217})* and low pressure (p_{218}) sides of the reservoir are equal. The amount of mercury in the reservoir will range from 241 to 281 lb during the course of 10,000 hours. For this condition, the system requires that 4.6 psia $\leq p_{218} \leq$ 14.6 psia.

The second condition is that concerned with the operating point where the TAA reaches 220 cps. The MPMA is operating at 4300 rpm and the pressure (p_{217}) at the high pressure side of the reservoir is approximately 154 psia. The amount of mercury in the reservoir will be in the range of 91.6 to 251.6 lb. For this condition, the system requires that the low pressure side (p_{218}) produce a pressure in the range of 6.9 psia $\leq p_{218} \leq$ 16.9 psia.

The third condition is that encountered when the TAA is up to design speed. While the system is stabilizing (i.e., while the boiler is conditioning and the TAA line is heating), the total amount of mercury in the reservoir will be in the range of 36.4 to 181.4 lb. The high pressure side (p_{217}) of the reservoir will be 510 psia and the low pressure side (p_{218}) must be within the range of 10.1 psia $\leq p_{218} \leq$ 20 psia. When the system stabilizes at full power operation, the reservoir will have 181.4 to 221.4 lb within it and the outlet low pressure from it must be in the range of 12.6 psia $< p_{218} <$ 13.4 psia.

---

*The p_{217} and p_{218} symbols refer to high pressure and low pressure sides of the reservoir.

These design limits are presently under study to determine the effect on the system dynamics. This is discussed in the section below.

(4) Dynamic Study Program

A digital computer program designated STRAP-1 (SNAP-8 TRansient Analysis Program) has been initiated to investigate the transient behavior of the PCS system during startup and shutdown operation. In particular, the objective will be to determine the suitability of the design limits assigned to the mercury reservoir as they affect the startup and shutdown procedure of the system. In addition, the design criteria for the flow-control valve and the controller will be generated from this study. At present, the computer program has been written and is undergoing checkout.

b. HRL Radiator Study

The computer program code for the optimization of the HRL radiator design has been completed and a technical memorandum on the subject is in the process of preparation. A description of the study with its objectives, geometry used, and assumptions, was presented in Ref. 4. The radiator studied was assumed to consist of a truncated cone section resting on a cylindrical section. The cone section is 92 and 144 inches in diameter at the top and bottom, respectively, with a slant height of 120 inches, while the bottom or cylindrical section is 144 inches in diameter and of variable height. The radiator is made up of 1/4 in. diameter tubes with attached fins of variable thickness. The tube diameter (1/4 in.) was found to be most efficient when compared to other tube sizes. The objective was to conduct a parametric study showing the effect of variations in fin thickness and number of tubes upon the overall radiator surface area and weight. Figure V-4 shows the results of the study. This study does not result in an optimum radiator configuration because such a study would of necessity include considerations of overall vehicle requirements, such as structural rigidity.

c. Lubricant/Coolant Radiator Program

The computer program for the lubricant/coolant radiator has been debugged and checked out. This program is similar to the HRL radiator program described above in its concept and assumptions. Because of different fluid properties, calculations for the film heat-transfer coefficients are different in the L/C radiator program. With minor change in inputs, a multiple-pass radiator configuration can be run with this program. The multiple-pass configuration seems to be necessary in view of the low fluid temperature and, therefore, low fin-radiation effectiveness. Studies based on PCS requirements are currently being conducted.

d. PCS Interior Heat Balances

An elementary study was conducted of the heat interchange between the PCS components and the internal side of the HRL radiator. For purposes of simplicity, the heat interchange between components was neglected. The heat interchange between each component and the radiator was calculated based upon different component insulation thicknesses and different radiator temperatures. The weights of the insulation were calculated.

For a typical case where the radiator temperature was $960^{\circ}R$ and where the components are covered with 1 inch of "Min-K" insulation ($k = \frac{.0072\ BTU}{HR\text{-}FT^{\circ}R}$), the overall net result would be a 0.8 kw transfer of heat from the radiator to the PCS.

2. General System Studies

a. System Performance with Dual PCS Operation

A study was undertaken to determine the net output power of a SNAP-8 EGS with two PCS units operating from the output of a single reactor. This mode of operation could occur when one PCS is being shutdown for maintenance or repair and the second PCS is brought on the line to provide the normal net power output of 35 kwe.

During the period when both PCS units would be operating, a net power output of less than 5 kwe would be produced if (1) the auxiliary components of both PCS units are utilized, (2) the turbine back pressure is kept at the present design operating level, and (3) the reactor power level limit of 600 kwt is maintained. Net power output values in excess of 10 kwe can be obtained if the turbine back pressure is reduced. However, this would require an increase in radiator size.

The study also included the effects of changes in certain hardware items on the net electrical power output. The results of this portion of the study indicate that 35 kwe can be obtained from the operation of a dual PCS unit if proper changes in hardware are made. The results of the overall study are presented in Ref. 7.

b. System Performance with 1200°F Reactor Outlet Temperature

The results of a study to determine the effects of a 100°F reduction of the nominal reactor outlet temperature on the net power output of the system was reported previously in Ref. 8 and 9. A supplementary analysis was conducted to determine the maximum net power output which could be obtained from a system during a ground test with a minimum of hardware changes.

The results of the latest analysis indicate that a net output of 20 kwe could be obtained from a system operating on the ground with no changes in hardware. The results of the analysis also indicate that no significant improvement in output power can be obtained without major changes in hardware. All required system operating conditions for a net output of 20 kwe were established as a result of this study and are listed in Table V-1.

3. <u>Computer Utilization</u>

Data obtained from the Digital Data Acquisition System (DDAS) during steady-state operation is analyzed using a computer code. However, the flexibility of the current code, SEDAN-X, is quite limited. A new computer code which is tentatively named SEDAN-XXX has been written and is being debugged.

4. PCS Design

The design criteria for the primary, mercury, and heat rejection loops were completed.

Design analyses of the primary loop gallery area continued. A new configuration (Figure V-5) has been analyzed and results in lower stresses at all interfaces. The new layout meets the requirement of the gallery envelope as presently defined. However, the requirement for drainage points has been increased from one to a minimum of three drainage points for the gallery area and the ability to remove components for maintenance without interference with other components has been limited. It also should be noted that a relatively small (3-in. dia. x 7-in. long) check valve has been assumed.

Thermal stress analyses of the mercury loop and the HRL are under way. The HRL analysis portion of the study has been completed and all stresses are below those permitted by the components. A major accomplishment of the design is the elimination of the bellows between the condenser and the turbine.

5. NS/PCS Integration

The NS/PCS integration activities during this report period consisted mainly of the assembly of nuclear system technical data and the writing of a nuclear system technical-interface control document. This document has been completed in review draft form and is scheduled for first draft issue during the next report period.

Atomics International has completed and informally provided, the results of a decay-heat-removal requirements study. The conclusions of the study are that active cooling of the reactor must commence within 8 seconds after initial primary NaK loop pump stoppage and must continue for 6 hours after shutdown of the reactor. The 6-hour requirement is based on limiting the peak fuel temperature to the nominal operating condition with stagnant NaK in the core. The study also included a review of the problems associated with having stagnant NaK in the loop and a large temperature difference between the reactor and the remaining portion of the primary NaK loop on restart of the system. When such a condition exists, flow rate through the core must be limited to very low values for the first 10 to 15 seconds on restart in order to limit the rate of temperature change into the reactor.

6. Support Equipment Activities

Three basic types of reactor simulator heat sources were subjected to investigation: (1) a cartridge-type electric heater, (2) an I^2R heater with resistance heating in the process fluid, and (3) a NaK/NaK heat exchanger with a separate NaK loop heated by a gas-fired heater. The original evaluation was based largely upon demonstrated reliability for long-term operation and resulted in a preference for the I^2R-type heater. Further study and the receipt of additional information indicated additional complexities associated with the I^2R heater. The reactor simulation requirements in regard to volume and pressure-drop resulted in a very high current, low-voltage power requirement. Control at lower power levels appears difficult and the large bus bars would require an involved cooling system. It was reported to LeRC that further consideration of the I^2R heater had been terminated and that the cartridge-type heater was preferred. At this time, no further work on the development of a reactor simulator is scheduled. If, in the future, development of the cartridge-type heater shows complexities not foreseen at this time, the NaK/NaK heat exchanger type simulator will be considered and possible reconsideration of the I^2R heater will result.

The ground service equipment (GSE) approach presented in the last Quarterly Report was pursued in more detail. Figure V-6 was prepared in order to indicate the AGC proposal regarding the connection of support equipment to the PCS. Attachment to the PCS, as indicated by the arrows on Figure V-6, does not necessarily mean that the support equipment is operating or that the PCS fluids are flowing through the support equipment. Equipment normally used to prepare the PCS for test operations would be isolated from the operating PCS by means of closed valves and would be readily available for use during PCS down times to prepare the PCS for further operation. The number of service carts remaining connected to the PCS are based primarily upon the amount of confidence in the PCS which is expected at that particular time. As additional confidence is developed, support equipment carts may be disconnected from the PCS since fewer shutdowns would be expected. The PCS will be designed for disconnection of the support equipment for eventual independent, integrated operation with the nuclear system and the flight radiator assembly.

B. MATERIALS SUPPORT ENGINEERING*

1. PCS-1 Phase IV Operation Support

A through-wall failure in one tube of the tube-in-tube boiler resulted in cross-loop leakage between the primary NaK and mercury loops. The foreign NaK and mercury were removed from both the NaK and mercury sides of the boiler, the turbine and the mercury loop piping and associated valves, using decontamination procedures appropriate to the individual component. The NaK primary loop, where the mercury content of the NaK was measured at approximately 10% by weight, the expansion and dump tanks, the NaK PMA and TSE equipment were cleaned of foreign mercury, again using procedures appropriate for each component. The NaK-loop piping was cleaned of mercury residue through dilution by circulation of several fresh uncontaminated (with mercury) inventories of NaK.

Post-failure analysis of various system components indicated that the gas-fired NaK heaters, the NaK PMA boiler, turbine and associated mercury vapor lines had not been detrimentally affected by the operating period with mercury in the NaK, and NaK in the mercury, loops.

*Under the terms of the SNAP-8 contract a materials report is prepared on a semiannual basis. The summary from the July through December 1966 materials report (Ref. 10) is included here. For specific details, the reader is referred to the complete report.

Continued periodic analysis of system fluid samples taken during Step 2 and Step 3 operation indicated the residues in the fluids were comparable to those found during earlier test periods. The mercury contained powder oxidation products, primarily iron oxides with some oxides of nickel and chromium. In addition, there were metallic particles of mild steel and 316 SS; organic residues also were found. The quantity of all these foreign materials did not appear to be excessive for continued operation, although they continued to indicate mercury corrosion product mass transfer, less than optimum fabrication and assembly procedures, and oil contamination from some still undefined source. Preliminary testing performed on the SNAP-8 mercury inventory currently stored in polyethylene bottles indicates some of this oil contamination may have resulted from an aliphatic hydrocarbon extending from the bottle wall. Follow-up tests were initiated.

Alkali metals in small quantities were again detected in the mercury. Previously, it was postulated that these were introduced by incomplete cleaning or through the use of NaK-contaminated instrumentation. It appears, in light of the boiler failure, that a miniscule leak may have existed for a considerable period resulting in this slight contamination of the mercury with the NaK.

Three commercially available automatic hand tube welders were evaluated to determine which possesses apparent optimum capability for welding tube butt joints of the SNAP-8 configuration. The unit produced by Astro-Arc Company, Sun Valley, California was judged to produce superior weld joint penetration control and joint quality. Purchase of this unit was recommended.

2. Refractory Bimetal Tubing

As a result of the change in the reference SNAP-8 mercury containment material from 9Cr-1Mo steel to tantalum, work was initiated to evaluate alternative methods of producing the required tubing. A bimetal construction (316 SS outer cladding with a tantalum liner) was selected for one conceptual design. In this manner the tantalum would be protected against NaK exposure in the boiler which might result in detrimental interstitial contamination and potential tube failure.

Initial evaluation of experiments to vapor-deposit tantalum on the inside surface of a tube indicate process feasibility. Tube material substrates of 9Cr-1Mo steel (for interim boiler use) and 316 SS (for subscale boiler tests in CL-4) are being used. The tantalum layer on the 9Cr-1Mo steel was found to contain a hard (approximately R_C70) interface diffusion zone on the tantalum side of an apparently adequate metallurgical bond. The tantalum thickness along the five-foot tube length was below the required minimum, but the thickness variation was within required tolerance. The high deposition temperature requires a subsequent tempering operation at 1350°F to produce the desired metallurgical structure in the 9Cr-1Mo steel. Initial experiments in a less-than-optimum argon atmosphere indicate that the ends of the tantalum liner (approximately 2 in.) sacrificially protect the balance of the tube by absorbing the greater portion of interstitial gases (O_2, N and H_2) in the argon.

After initial process development experiments, a five-foot tantalum/316 SS bimetal tube was produced by explosive bonding. The process being developed requires no subsequent cold drawing operation since the tubes are bonded to final size for use as the SNAP-8 boiler mercury containment tube. The experimental tube is being ultrasonically tested for bond detection.

3. Turbine Materials Evaluation

Elevated-temperature tensile tests up to 1250° were conducted on Stellite 6B (a cobalt-base alloy) specimens in the FCC and HCP crystallographic structures. The HCP structure was produced by pretest thermal exposure at 1650°F for 4 hours followed by up to 1500 hours at 1450°F. The tests confirmed the previously presumed extremely low ductility of the HCP (3.7% elongation at 1200°F) structure compared to the FCC structure (15.0% elongation at 1200°F).

It was considered inadvisable to retain Stellite 6B as the reference turbine aerodynamic material, and a change was made to S-816, another cobalt base alloy. The new reference material exhibits metallurgical stability at temperatures up to 1200°F, and has a proven reliability through general use in the gas turbine and aircraft engine fields.

Because S-816 is not readily weldable, 19-9DL, an austenitic stainless steel, was selected for the second-stage nozzle diaphragm requiring welding which would not be exposed to high mercury corrosion or erosion potential. A fabrication study was concluded which indicated that the assembly could be produced to final machined dimensions and tolerances if 1/32-in. stock was left on all final machined surfaces to compensate for distortion and warpage produced during electron-beam welding and heat treatment performed prior to final machining.

4. Component Failure Analysis

A post-failure analysis of the tube-in-tube boiler after a total of 587 hours of mercury loop operation was completed. The failure in one mercury containment tube at the boiler outlet was attributed to a high bending stress caused by differential thermal expansion of the materials of construction; 9Cr-1Mo steel and 321 SS. The imposed stresses were further increased because of the presence of stress concentrations introduced during boiler fabrication. Wall thinning of the 9Cr-1Mo steel tubes and metal removal from the mild steel inlet plug appeared to have resulted from either mercury corrosion/erosion or mechanical damage during fabrication, or a combination of these. Ancillary tests indicated a minor contributor to the metal removal from the mild steel plug was probably a two-time, one-minute exposure to circulating nitric acid during boiler mercury-side chemical cleaning for removal of decomposed mix-4P3E.

After 168 hours operation of the NaK-to-NaK heat exchanger, a failed 316 SS thermocouple well was found and evaluated. The failure apparently occurred at a weld which jointed the tip of the well to the body. The primary cause appeared to be an increase in internal pressure probably resulting from elevated-temperature decomposition of a contaminant, probably an organic, sealed inside the well. The resultant high internal pressure induced a wall stress in excess of the allowable for the 316 SS, ultimately producing a rupture.

Metallurgical evaluation of the Inconel X spring in a failed HRL temperature control valve indicated no material deficiencies in the Inconel X material. Subsequently, a stress analysis indicated the failure was due to overstressing of the spring during component operation which produced an unacceptable permanent set. Redesign of the spring was required to reduce the imposed stress to an acceptable level.

A crack in one diaphragm of a 410 SS bellows was found in an unpressurized MIS. The failure analysis indicated the probability of a stress corrosion failure induced by an inadequate heat treatment of the bellows material in combination with incomplete dehydration of the unit. Appropriate changes in heat treatment and assembly procedures should prevent a future similar failure.

5. Corrosion Loop Program

A mercury capsule wetting test program was completed which established a procedure for producing immediate wetting of 9Cr-1Mo steel mercury boiler containment tube upon startup. It was indicated that 9Cr-1Mo surfaces could be wetted with mercury by exposing the surface to a Hg-Li solution (100 to 500 ppm lithium Li) at a temperature of 950°F for four hours. It was also determined that an argon atmosphere did not interfere with the wetting procedure during the 950°F soak period. It appears feasible to pretreat a boiler mercury containment tube so as to obtain immediate wetting, and consequently acceptable mercury-side heat transfer on boiler startup.

The CL 4A-2 test section completed a 306-hour boiler operation test in CL-4. This section contained a tantalum plug and a metallurgically bonded Cb/316 SS bimetal tube (316 SS outer cladding) fabricated by coextrusion and cold drawing the tube extended over the tight-pitch (4.5 fps mercury velocity) length of the section. The vapor qualities calculated from the test data were greater than the predicted design values.

Prior to the test, the bimetal tube indicated a 100% bond using the ultrasonic test technique. After operation, the tubing indicated a poor bond over 50% of its area. The predominant area of debonding was approximately 17 inches from the mercury inlet.

Measurement of the tantalum plug and the wall thickness and outside diameter of the Cb/316 SS tubing indicated no change in dimensions.

A sample of the Cb liner from the Cb/316 SS tubing was analyzed for hydrogen, nitrogen, and oxygen before and after operation in the test section. There was no significant pickup of these interstitial gases during the loop operation.

The CL 4A-3 test section was operated in CL-4. The section is fabricated completely of 9Cr-1Mo steel, and represents the current reference boiler inlet section design producing 4.5 fps liquid mercury velocity.

The test section was prewetted using a Hg-Li solution (574 ppm. Li) treatment which produced an improvement in the performance of the boiler inlet plug section as indicated by the NaK temperature profile. A corrosion run was started but was aborted after 120 hours of a scheduled 300-hour run because of a high ΔP which developed during the operating period in the inlet plug region (increased from 37 to 52 psi at 550 lb/hr mercury flow).

Tube wall loss was found in areas where deposits had not built up, but no apparent corrosion of the inlet plug occurred.

The CL 4A-1 test section was prewetted using a Hg-Li solution containing 538 ppm of Li lithium and was then run for 304 hours. This section was fabricated entirely of 9Cr-1Mo steel as the CL 4A-3 section, but a revised plug design produced a liquid mercury velocity of 1.1 pps.

Corrosion product buildup occurred in the grooves at the end of the plug; however, during this test, no effect on the boiler performance was noted from the corrosion product deposition. A swaging process was successfully used on this section to eliminate the clearance between the inlet plug outside diameter and the tube inside diameter so that bypass mercury flow between channels apparently did not occur.

Comparing the results of the CL 4A-1 and CL 4A-3 test sections, it is apparent that the corrosion rate in the preheat region can be reduced by decreasing the liquid mercury velocity.

The CL 4A-4 test section was prewet using a Hg-Li solution (617 ppm lithium) and was then run for 304 hours. This section was fabricated with a tungsten orifice, replacing the tight-pitch section of the plug which was so designed as to produce a liquid mercury velocity of 0.2 fps through the preheat section. After the test, it was found that the orifice carrier, which was made of 9Cr-1Mo steel, had been corroded away allowing mercury to bypass the orifice. Because of the orifice carrier corrosion, the heat-transfer performance of the test section and the effects of extended operation could not be evaluated from this test.

Fabrication of the CL 4C-1 test section was started. This section consists of refractory bimetal mercury containment tubing, and a tantalum inlet plug. The assembly is fabricated by swaging (cold) a 316 SS tube over a tantalum tube, this in turn is swaged over the tantalum inlet plug. Thus, an interference fit is established between the tantalum and 316 SS tubes but no metallurgical bond is formed. The purpose of this test is to evaluate the heat-transfer performance of an unbonded bimetal mercury containment tube.

6. <u>Modified 9Cr-1Mo Capsule Creep</u>

Design was complete on a creep capsule, outer capsule, gas system, and a creep-measuring system for performing a capsule creep test on modified 9Cr-1Mo steel in a NaK environment. This work was suspended as a result of a change in the reference SNAP-8 mercury containment material from 9Cr-1Mo steel to tantalum. Work also was performed to develop an alternative to the standard 9Cr-1Mo steel heat treatment which would produce the most stable metallurgical structure for resisting creep in the operating boiler environment. Tests indicated that the optimum alternative heat-treat cycle to the established standard (1900°F normalize followed by 2-hour temper at 1350°F) is a 1900°F normalize followed by a 2-hour temper at 1400°F.

To determine the effect of a relatively long-term exposure at the boiler operating temperature, samples, heat-treated through each cycle, were put in a 1325°F furnace for 100 hours. The hardness indicates that the samples were relatively stable - none of the samples dropped to the annealed hardness level.

7. Corrosion Mechanism Study

The corrosion mechanism loop was operated to evaluate two prime theories proposed for 9Cr-1Mo corrosion by mercury. If that theory applies which includes a dependency of liquid mercury velocity on the corrosion rate, then the test also would establish the relationship between these factors. The test sequence was started, but difficulty was experienced in achieving mercury wetting of the 9Cr-1Mo specimen surface using a Hg-Li solution. The test run of 200 hours was ultimately completed without confirming optimum mercury wetting. Evaluation of the test sections was started, but interpretation of results will be difficult because the test sections were not wetted throughout the 200-hour test.

C. SEVENTH SCALE LOOP

1. Introduction

The Seventh Scale Loop (SSL) is being designed and fabricated at San Ramon as part of the Small Scale Boiler Phenomena (SSBP) program (Ref. 11). The overall goals of the SSBP are to investigate and develop solutions for the following SNAP-8 boiler problem areas: (1) boiler conditioning, (2) extended boiler lifetime of 10,000 hours, (3) operational stability, and (4) elimination of liquid carryover. The SSL will provide a facility for testing full scale single-tube boiler test sections. Heat transfer and fluid flow data from these single-tube modules will be directly applicable to the SNAP-8 boiler geometry which incorporates seven parallel mercury boiling tubes.

During this past reporting period, the emphasis in the SSBP has changed from that of optimizing the operating parameters and design geometry of a SNAP-8 boiler constructed of 9Cr-1Mo material to that of obtaining test data on refractory metal boilers. To establish a basic datum plane as well as effect an early loop startup date, the first SSL boiler test section will be the 9Cr-1Mo reference SNAP-8 T-T boiler geometry (designated SA-1). Testing of bimetal (Ta/SS) and bare refractory boilers will follow.

2. Mechanical Design

a. General System Description

The facility can be best described by referring to the Piping and Instrumentation Diagram,(Figure V-7). The facility consists of two separate loops, one mercury and one NaK, which are connected at the boiler. Within the boiler, flow of the two fluids is counter-current in two concentric tubes. To satisfy a portion of the test plan which requires parallel flow in the boiler preheat zone, the outer jacket is interrupted and crossover piping and valves are provided so either flow arrangement can be obtained. The outer jacket is interrupted at four additional sections so that pressure and temperature taps can be added to the mercury tube. The temperature of the mercury stream at the boiler inlet is automatically controlled by the mercury preheater. At the boiler inlet there are also taps for withdrawing mercury samples, for injecting oil for special tests and for measuring temperatures and pressure. The flow rate to the boiler is automatically controlled by an air-operated valve between the preheater and the pump discharge. This same length of line also includes a flow measuring element. The pressure in the boiler is controlled by a valve at the exit. This valve is electric motor operated but manually controlled. The exit line also includes temperature and pressure taps and room to install devices to eliminate liquid carryover. The exit stream from the boiler is condensed and sub-cooled in an air-cooled heat exchanger. The air flow rate can be controlled manually by adjusting baffles in the blower inlets. The air is ducted into and out of the cell from outside the building. The sub-cooled liquid flows by gravity to the suction of the centrifugal pump which is of the canned rotor type. On this same line rides a surge tank which allows the mercury inventory in the loop to adjust itself. The mercury in the tank is pressurized with nitrogen to provide sufficient NPSH for the pump. The discharge of the safety rupture disk on the loop is lead through a baffled vapor trap to prevent mercury contamination of the cell atmosphere in the event of disk rupture. The normal design point of the pump is so far from the reference conditions for the loop that a cooled bypass is required to control the temperature of the pump. The flow rate in the bypass is measured and is controlled by a manually operated valve. Filling the loop is accomplished by loading the surge tank, then evacuating the loop and forcing the mercury from the tank with nitrogen pressure. Draining the loop back into the dump tank is by gravity. All lines are designed with sufficient slope to allow complete drainage. All lines and connections to equipment are welded to minimize leakage. All valves have welded bellows seals on the stems. All lines and equipment in mercury service below 600°F are of stainless steel Type 316. For service above 600°F, 9% Cr-1% Mo steel is used. The first model boiler will be of 9Cr-1Mo steel; however, other models are planned using refractory metals and stainless steel. A sampling system is provided for sampling the mercury stream at the boiler inlet. During a test run samples would be collected in sample vessels for subsequent removal and analysis following the test run.

The NaK loop provides heat for boiling the mercury. This heat addition method simulates the SNAP-8 system. The NaK heater is made in three sections, each separately controlled. This division is made to give better control and to balance the load for the three-phase electric power input. The last section before the boiler is automatically controlled to keep the temperature steady. The line to the boiler includes a device to mix the flow so that an average bulk temperature will be measured. This line also includes a surge tank which allows expansion space for the NaK when it expands upon heating. The tank is given an over-pressure of argon so that no boiling occurs anywhere in the NaK loop. The heat transferred from the NaK to the mercury in the boiler is determined by computing the enthalpy change. This computation is made using data from thermocouples spaced on the outside of the NaK tube along the length of the boiler and from the data of the flow measuring element placed at the exit of the boiler. The signal from the flow sensing element also is used to control the flow rate of the pump.

Before any test runs are made, the NaK is purified of oxides in a bypass purification loop in order to minimize the occurrence of plugging and corrosion. Since the solubility of oxides in NaK is known as a function of temperature, the amount of oxides in solution after purification can be measured by controlled cooling of a sample flow in a special heat exchanger until precipitation occurs in a "plugging indicator valve" located downstream of the heat exchanger. The loop is filled by loading the dump tank, evacuating the loop, then forcing the liquid into the loop by pressurizing the dump tank with argon until the liquid level device in the surge tank mounted at the top of the loop indicates a full system. The NaK is drained from the loop back to the dump tank by gravity. All lines are sloped for complete drainage. All lines and connections to equipment are welded to eliminate leaks. All valves have welded bellows seals on the stems. All lines and equipment are stainless steel Type 316 except for the NaK jacket on the boiler. This tube is 9% Cr-1% Mo steel, the same as the mercury tube in order to alleviate differential thermal expansion problems of dissimilar metals.

The facility is being installed in an enclosed, ventilated room at San Ramon. The ventilation air removes the heat lost through the insulation and keeps the atmosphere clean so that the cell can be entered when the tests are complete. The ventilation air is exhausted through a scrubbing tower for removal of any mercury residue before discharge outside the building. The concrete floor is painted with a strippable paint to aid in mercury decontamination. In addition, all floor area underneath and immediately adjacent to all NaK equipment is covered with a steel pan to contain any NaK fire. The walls of the cell are covered with strippable paint to aid in mercury decontamination. The walls include plexiglass windows for complete inspection of the interior and are pierced only to admit ventilation air and for valve extension handles.

The nominal mercury flow rate will be 1680 lb/hr which was determined as one seventh of SNAP-8 reference conditions. In order to test for a heat-transfer correlation, the mercury flow will be varied up to a maximum of 2000 lb/hr. The NaK flow rate will be 9000 lb/hr. The mercury temperature at the boiler usually will be 500°F which is SNAP-8 reference condition; however, it will be possible to run tests with the inlet temperature all the way up to saturation. SNAP-8 reference requires boiling to initiate at 315 psia (T_{sat}=1100°F). If the test boiler conditions and operates as reference, the pressure at the exit will be 270 psia (T_{sat}=1070°F) and will be superheated to 1280°F. In this case the pressure will be reduced by the exit valve to 15 psia so that the condenser will operate at 680°F. The NaK stream will enter the boiler at 1300°F and exit at 1100°F.

b. Mechanical Design Activities

The equipment arrangement design is represented by Figures V-8 and V-9. Figure V-8 shows the plan view and one vertical section. Figure V-9 includes a list of detail component drawings which have been completed. Design analyses have been done for each component.

The boiler length was selected at 30 ft to simulate the SNAP-8 reference length. The inner tube (mercury side) diameter and wall thickness also are SNAP-8 reference geometry. The outer tube (NaK side) diameter was computed using the criteria that the heat transfer coefficient in the annulus should match the coefficient in the SNAP-8 boiler. The internals of the mercury tube will be designed as part of each test boiler. The allowable stress for active forces where appropriate conditions were combined was selected as the stress which causes creep of 1% in 10,000 hours.

The purpose of the first SSL test section (SA-1) is to determine the performance of the reference SNAP-8 boiler geometry. The heat transfer analysis of the plug insert region is given in Ref. 12. The test section assembly is shown in Figure V-10.

The test section is a single pass tube-in-shell heat exchanger. The NaK shell is made of 1-1/2 in. OD x 1.334 in. ID 9Cr-1Mo tubing. The mercury tube is made of 0.832 in. OD x 0.652 in. ID 9Cr-1Mo tubing centered in the NaK shell by spacers. The plug insert is placed at the mercury inlet to promote heat transfer and boiler stability. The mercury flow passage throughout the plug insert is single channel and multipitch with the following geometry:

<u>Preheat Region</u>:

Pitch - 3/8 in. (machined thread)
Axial length = 12 in.
Flow area = 1.339×10^{-4} ft^2

<u>Low Quality Region</u>:

(a) Pitch = 2 in. (wire wound)
Axial length = 6 in.
Flow area = $5{,}985 \times 10^{-4}$ ft^2

(b) Pitch = 4 in. (wire wound)
Axial length = 36 in.
Flow area = 7.7×10^{-4} ft^2

The boiler tube will be swaged over the plug insert to eliminate inter-channel leakage.

A 0.062-in. diameter wire turbulator is placed downstream of the plug insert. Two pressure sensing taps, one at the middle of the tight pitch region and the other at the end of the tight pitch region, are provided to facilitate heat transfer and pressure-drop analysis. The total length of the test section is approximately 80 in.

The mercury condenser was designed for the heat load using a heat transfer coefficient for the air side determined from Kays and London, "Compact Heat Exchangers," McGraw-Hill (1958). The condensing coefficient for mercury condensing was assumed to be 50% of the boiler coefficient which was found during previous tests. An analysis was made of the differential thermal expansion between the nickel fins and the 9Cr-1Mo tube to determine the initial interference fit required to preclude separation during operation. A simple test was run to substantiate the calculations. Stress due to both active and passive loads were analyzed, using as an allowable the stress to cause 1% creep in 10,000 hours.

The mercury pump was selected for being commercially available and for being available as a spare from other SNAP-8 loops. The normal design point of the pump is much greater than the performance required by the loop; however, with the addition of a bypass cooler to account for the low efficiency due to operating the pump close to shut-off and a flow-control valve with a properly selected C_v, performance can be matched to requirements. The pump has the advantage of having zero leakage due to its canned rotor design.

The heat load of the mercury preheater was determined from the requirements of the test program. Several configurations were considered. The configuration with commercially available semi-cylindrical, radiant electrical heaters surrounding the mercury tube was selected because it was the simplest and cheapest, and had been successfully used before. The number of heaters required was determined from calculations using the criteria that the temperature limit of the heater coils not be exceeded. A "Z" shaped configuration was selected to conserve floor space and to alleviate thermal expansion problems between anchors.

The mercury bypass cooler was designed as a concentric tube, counter-flow heat exchanger using commercially available tubing fittings.

The heat load was determined from the pump efficiency curves. The heat transfer operation of the water side (the annulus) was arranged so that the temperature of the inner tube remained below 130°F to prevent fouling.

The mercury sample system was designed to allow four separate samplings to be taken during any test run without shutting down. Volumes were checked to ensure that the mercury inventory in the loop would not be affected. The flow rate during purging was designed so as to leave the loop unaffected. Care was taken not to introduce extraneous products into the sample from the feed lines and to keep the temperature constant so as not to have material from the sample precipitate in the lead lines. The sample holder was designed to catch a representative sample.

The NaK pump (GE Model SKY414PR1) was selected for being commercially available and specifically designed for the intended service. The design point was determined by calculating the pressure drop for all lines and components in the circuit. The vendor's catalog data closely match the desired performance.

The heat load of the NaK heater was determined from the requirements of the test program. The tubing which acts as resistance elements was selected from commercially available sizes. Heat transfer calculations were made to ensure that tube wall temperatures were below 1350°F. The temperature pattern in the bus bars was analyzed to ensure that the tube end matched the fluid and that the end connected to the copper circuit was below 300°F. The insulation package around the coils was designed to limit heat loss to a reasonable value. The structure was designed to support the coils with minimum induced loads. Stresses in the coils and the structure were analyzed. In this case, the allowable stresses were determined from the ASME Pressure Vessel Code, Section VIII.

The NaK purification system was designed to the criteria that the saturable oxide level must be reduced to below 20 ppm. The free convection air-cooled cold trap was analyzed to ensure that minimum temperature would be 250°F. The operation of the system was analyzed to determine that the speed of the process was sufficient to purify the volume of NaK in the loop within 24 hours. The volume available in the cold trap for precipitate was sized to be sufficient for several years of loop operation. The design of the cooling circuit used to determine the oxide level in the loop was taken from one being used successfully in another loop at San Ramon.

The lines interconnecting the components for both the mercury and NaK loops were designed for all welded construction. It was decided not to use expansion bellows in order to improve the system reliability; therefore, most lines include expansion loops. A computer code, TVCS-3, written by the Tennessee Valley Authority and supplied under the "Share Plan", was used to calculate stresses, deflections and rotations in the pipe sections, and anchor reaction forces and moments.

Valves were selected principally on the basis of welded bellows sealed stems and proven service in high-temperature liquid metal installations. Thickness of insulation was designed to hold the system heat loss to a reasonable value.

Use of an existing, portable lithium-injection system for conditioning the boiler was investigated and deemed adequate for SSL applications.

An oil injection system to simulate off-design conditions in SNAP-8 has not been designed but provisions have been made for its attachment when desired.

A design for connecting to the existing plant cooling water system has been made.

Structures have been designed to support all components and to serve as anchor points in the piping system.

3. Instrument and Electrical Design Activities

Design of the instrumentation and electrical system was based on the use of existing SNAP-8 equipment and facilities wherever possible. Therefore, a substantial amount of corrosion loop equipment was incorporated in the design. This equipment included recorders, controllers, electrical contactors, relays and various panel-mounted instruments. For ease of operation, the instruments and controls used for the SSL are located in the corrosion loop console but are grouped to allow separate operation of either system (see Figure V-11). The following instrumentation, controls and electrical system design were accomplished during this report period.

a. Instrumentation System

Design of the instrumentation system was completed except for the instrumentation of the SA-1 plug. Measurement channel locations have been determined and readout points for process system monitoring have been assigned. All thermocouples, pressure transducers, process recorders, and signal conditioners have been received. Thermocouple extension wire and two multipoint records are on order but have not been received.

b. Control and Electrical Power Systems

Design of the control and electrical systems is approximately 90% complete. Design changes allowing the use of the Mine Safety Appliance (MSA) Style VIII electromagnetic NaK pump are in progress. Design of all other control and power systems is complete.

The safety system is designed to shut the entire loop down in the event of component or system failure. However, loop operation will resume if power fails for less than one second. The safety system is shown on Figures V-12 and V-13.

The NaK heater control is designed to control the NaK heater outlet temperature automatically. High temperature shutdowns on each section of the heater will shut the loop down if any temperature exceeds the set point.

The reference NaK flow-control system, using the GE pump, is designed to control flow automatically and to compensate for line power fluctuations within a few cycles. However, a strike of unknown duration at the GE plant has caused indefinite delay in the pump delivery, thereby requiring the substitution of an existing MSA Style VIII pump system with manual control for initial loop operation. This system will be equipped with an automatic control to operate the motorized variable transformer. However, flow variations in the order of $\pm$ 10% can be expected. This system will be useful for allowing the loop to be checked out and to operate until the GE pump system has been received and installed.

The mercury flow control uses a differential pressure sensor and an electro-pneumatic control system to automatically position the flow-control valve for the desired flow. All components for this system have been received.

The boiler pressure-control system is designed to control the boiler pressure using a variable area nozzle with a motorized positioner. Pressure will be controlled manually from the control console. Delay in obtaining the control motor and suitable bellows has caused the delivery of the choke nozzle to slip past the scheduled installation date. Accordingly, a manual backup nozzle which was used in the AGN CL-2 will be reworked and installed for loop checkout and initial operation. The motorized choke nozzle will be installed when received.

The mercury preheater system is designed to automatically control the mercury temperature into the boiler. This system uses a saturable core reactor to control the power input. All components have been procured.

All trace heaters and purification system heaters will be manually controlled. Power will be turned on and off at the control console and regulated with a variable transformer. All components have been procured.

4. X-Ray Development

A development program was carried out to determine the feasibility of determining the mercury liquid-vapor interface in a 9Cr-1Mo boiler by X-ray image amplifier techniques. Because of the sporadic behaviour of mercury boilers, the precise location of the liquid-vapor interface has been difficult to predict. Two X-ray generators were utilized in this development program: A GE 140 kv generator with 2 mm focal spot and a GE 250 kv generator with 5 mm focal spot. A mockup of the reference 9Cr-1Mo boiler configuration, complete with insulation, was constructed as shown in Figure V-14. The assembly was mounted vertically and a 4-inch layer of Johns-Manville insulation was placed around the capsule.

Initial testing with the 140 kv generator failed to yield any definition of the internals of the test specimen. Figure V-15 shows the test setup for the 250 kv X-ray head. An adjustable lead collimator was attached to the GE X-ray head to localize the X-ray beam. A lead collimator shield also was placed over the image tube face to allow only the beam, which passed through the boiler section, to reach the phosphor screen of the image amplifier. A copper filter placed in the X-ray beam also helped to reduce scatter on the screen by blocking the softer X-rays.

Figure V-16 shows a representative photograph of the image as viewed on the remote TV monitor. Excellent contrast was obtained between the mercury and non-mercury areas. The sharpness of detail above the interface could stand improvement in order to discern details of liquid carryover in the dynamic condition. This feature would be obtainable through the use of an X-ray tube with smaller focal spot size.

A 300 kv Norelco X-ray generator with 1.0 mm focal spot is expected to be available during the first week in January for use in the SSL.

5. <u>Component Fabrication and System Assembly</u>

a. Mechanical

During the report period, major emphasis lay in procurement of long lead items and component fabrication. Certain delays were encountered in several long-lead items which required substitution of other equipment. The three-phase electromagnetic (EM) pump ordered from GE was delayed as the GE plant went on strike in October and was still non-productive at the end of December. A delay also was encountered in procurement of the special three-phase power control unit to be used in conjunction with the GE pump when the delivery schedule slipped from 8 to 15 weeks prior to placement of the purchase order. Accordingly, it was decided to substitute an existing SNAP-8 MSA EM pump with motorized powerstat for initial loop operations.

Several procurement actions were unsuccessful in getting outside vendors to bid on the mercury finned-tube condenser. Accordingly, it was decided to build the condenser in-house. A process was developed for shrink-fitting the Nickel-A fins onto the 9M tubing. Final assembly of the condenser is under way and should be completed in early January.

Installation of the air-cooling system for the mercury condenser was completed except for the duct sections which connect to the condenser. These items will be completed following condenser installation.

Final assembly of the multi-section superheater portion of the mercury boiler is under way and should be completed the first week in January.

Final assembly of the NaK heater is under way. Bus bar terminals and heater housing (Figure V-17) have been fabricated. Delays were incurred in getting the heater coils bent within tolerance by the outside vendor. At the end of this report period the coils had been received. Final assembly should be completed in early January.

As shown on Figures V-18, V-19 and V-20, many smaller components have been fabricated for the NaK and mercury system. A dump tank, surge tank, bypass cooler, preheater tube with support, and flow mixers have been fabricated for the mercury loop. Components which have been fabricated for the NaK system include cold trap, plugging indicator cooler, surge tank, plugging indicator valve, and flow mixers. An existing tank was modified for use as the NaK dump tank.

b. Instrument and Electrical Fabrication and Assembly

Instrument and electrical fabrication and assembly is progressing on schedule with the exception of the choke nozzle and electromagnetic pump-control unit.

As shown in Figure V-21, the control console instrument relocation to separate CL-4 and SSL controls is complete. All panels have been fabricated and installed in the racks except the multi-point recorders. Rack wiring is in progress. Wiring completed and in process of being checked out is the power and safety interlock control system and the patch panel. Wiring of the annunciator and automatic controllers is in progress.

Cables for the pressure transducers are partially fabricated. The thermocouple extension cable and thermocouple connectors have not been delivered.

As shown on Figure V-22, installation of electrical contactors and power-control relays is complete. Conduit installation between the power panels and the contactor panel is approximately 80% complete. Installation of the power circuit breakers and power wiring to the contactor panel has started. Conduit and wiring installation between the starter panel is approximately 20% complete and is waiting for cell equipment installation.

Fabrication of the bus bars for the NaK heater has been completed and they are ready for installation.

Instruments located in the cell will be installed as soon as the piping and equipment installation allows.

D. RELIABILITY ENGINEERING

1. Reliability Program Management and Control

The Reliability charter and program plan were again reviewed and updated to reflect the latest SNAP-8 program orientation.

Work was initiated on a parts history system in coordination with the Test Operations Department. This system will be used by Reliability in conjunction with the failure reporting system to provide complete historical records on parts and instrumentation. These records will provide the operating time, installation and removal dates, and other related information necessary for accurate reliability assessments, and for determination of inventory requirements.

A new report format for summarizing technical progress on failure corrective actions for use in PMR's was designed and implemented. Together with the revised failure reporting and corrective action procedures and flow chart described below, an efficient system for the control and correction of failures has been effected.

2. Reliability Statistics

a. Assessments

Two reliability assessment reports were made, one covering PCS components, and the second covering selected TSE equipment.

Reliability assessments were made on four PCS components; two components have accumulated sufficient time since the previous assessment to warrant reassessment and two that were not included in the last evaluation have considerable operating histories. Results of the four PCS components assessed were as follows:

Component	Test Hours	Number of Applicable Failures	MTTF at 50% Confidence	Hours Required in Mission	System Quantity
NaK PMA	5119	7	670 hr	10,000	2
L/C PMA	8669	0	12,500 hr	10,000	1
Voltage Regulator*	544	0	780 hr	10,000	1
Speed Controller*	541	0	780 hr	10,000	1

*Combined from Low Temperature Control Assembly and Transformer-Reactor Assembly.

A memorandum was issued covering the assessment of eleven TSE heaters, coolers and pumps. The mean-times-to-failure given below correspond very well with those calculated from data available from standard sources.

Component	Number of Operating Hours	No. of Failures	Failure Report (FR) Number	Est. Mean Time To Failure (Hr)
Gas-Fired Heaters	7,500	0[a]		10,800[b]
Prim. NaK EM Pump	5,800[c]	1	0197	3,500
HRL EM Pump	3,275[c]	2	0101,0141	1,200
Hg S.S. Vac. Pump	2,770[c]	1	0434	1,600
Hg Dump Tank Vac. Pump	2,770[c]	0		4,300
TAA S.S. Vac. Pump	2,770[c]	0		4,300
TAA Alt. Cav. Vac. Pump	2,770[c]	1	0158	1,600
TAA Lift-Off Vac. Pump	2,770[c]	0		4,300
L/C Mech. Vac. Pump	5,540[c]	1	0183	3,300
HRL Cooler	3,275[c]	0		4,700
L/C Cooler	5,540[c]	0[d]		8,000

[a] Two controller failures were experienced which resulted in heater but not loop shutdown (1-25-66 and 4-7-66).

[b] Does not include potential wearout failure.

[c] Times are estimated as multiples of mercury loop time.

[d] Regulator failure, FR 0162, caused cooler failure but not loop shutdown (7-12-66).

b. Test Operations and Analyses

A TM (Ref. 13) on evaluation of PCS-1 phase IV Step 2 testing using analysis of variance was issued. The memorandum covers evaluation of selected test data on HRL condenser inlet temperature, condenser inventory, and mercury and HRL NaK flow rates and their effects on output parameters. Conclusions of this study were as follows:

1. Condenser inlet pressure is affected to a greater extent than the other output characteristics by changes in the four input parameters. Boiler mercury outlet temperature is affected the least. Effects of the changes on all output characteristics are summarized in Table 1 of Ref. 13.

2. Due to the nature of the tests wherein system constraints limited the testing to particular sets of conditions and a symmetrical matrix of tests was not possible, some of the advantages of ANOVA delineated in Ref. 13 were not fully realized. However, the ANOVA still provided systematic diagnosis of cause-effect relationships and their significance.

3. There are definite advantages to using the same HRL flow rates for at least two sets of test conditions. This would eliminate the need for normalizing the HRL flow when evaluating the effects of both mercury and HRL flow rate changes on output parameters.

4. Substantial time savings in the analysis can be realized when the physical system constraints permit the performance of a complete matrix of tests.

c. Special Studies and Reports

A topical report on application of the method of bounds for reliability prediction was initiated. The report covers both a general discussion of the method and its advantages and a specific application to evaluation of candidate PCS redundant primary loop configurations. The report will be issued during the next reporting period.

The probability of an uninterrupted 90-day run of PCS was calculated, using a graphical approach to the Monte Carlo process. The calculations show that a system mean-time-to-failure of about 1000 hours is required to attain an 80% probability of achieving at least one uninterrupted 90-day test in 10,000 hours of loop operating time. A computer program, based on the Monte Carlo process, was later developed and utilized to confirm the validity of the graphical method. In anticipation of more sophisticated future needs, this program was then expanded to permit variations in the three parameters; total test duration, uninterrupted time requirement, and system MTTF.

d. Component Support

The reliabilities of voltage regulator parts (diodes and resistors) as affected by temperature and radiation level changes were analyzed. Effects of a temperature rise of 50°F and an increase in radiation by a factor of 10 were determined. The total effects of these changed conditions were as follows: a 250 to 500% increase in diode failure rate but only a 25% increase in the failure rate for resistors. The change in temperature results in an average failure-rate increase of only about 25% for both diodes and resistors. The increase in radiation level had little effect on the failure rate of the resistors but changed the diode failure rate by a factor of 200 to 400%. An additional 10°F change in the temperature level was computed to increase the overall increase in diode failure rate to 260 to 520% instead of the 250 to 500%.

Spares requirements for PCS-G primary loop elements were estimated based on a 15,000 hour lifetime requirement. Percentages of additional redundant elements required were computed using Chebychev's inequality for the five cases listed below:

Case	Wearout Safety Margin k (Standard Deviations)	Percentage of Additional Redundant Elements
1	2	50%
2	3	25%
3	4	15%
4	5	10%
5	>5	5%

Illustration: Assume that a 15,000 hour lifetime is required and that the elements have a mean-time-to-failure of 30,000 hours and a standard deviation of 5000 hours. The safety margin, k is then equal to $\left(\frac{30,000 - 15,000}{5,000}\right) = 3$. For k = 3, 25% additional elements are required. Thus, if 144 elements are needed to provide sufficient heat, a total of 180 elements should be procured (144 x 1.25 = 180).

Technical review was made of a report on instrumentation error analysis. The concepts of accuracy and precision were clarified, and the need for more information on instrumentation capabilities was discussed and recommendations were made.

3. Reliability Engineering

a. Design Support

The relative merits of welded and back-brazed vs rolled and welded condenser tube-header joints were evaluated. The rolled and welded configuration was recommended as superior with respect to reliability. Strict control of manufacturing and assembly is a requisite to assure reliable assemblies.

An initial Failure Modes and Effects Analysis (FMEA) was issued on the SNAP-8 turbine, P/N 098500. The four most prevalent modes delineated were; (1) structural failure by thermal stress, (2) structural failure by progressive fracture, (3) excessive rubbing of thrust balance and labyrinth seals, and (4) thrust balance and labyrinth seal leakage. It is expected that this FMEA will be used as a guide in the preparation of future FMEA's.

4. Operations Evaluation and Failure Analysis

a. Failure Reporting, Analysis, and Corrective Action System

Division procedures VI-A4c on failure reporting, and VI-A8a on failure analysis and corrective action, revising earlier editions, were completed and issued. These revised procedures increase the effectiveness of the failure reporting activity cycle and provide for scheduling all related activities on critical and major failures.

A flow diagram (Figure V-23), depicting the closed loop from initial failure through failure reporting, corrective action, and verification, was prepared. All corrective actions involving a Class I design change will have Configuration Control Board review and approval before implementation.

Cumulative operating times for major PCS components were summarized and provided to NASA-LeRC on a monthly basis. Cumulative operating times for these components through 31 December 1966 are shown in Table V-2.

E. QUALITY ASSURANCE ENGINEERING

1. QA Planning and Engineering

AGC was notified by NASA that the SNAP-8 Quality Program Plan, Report 3216, dated 1 September 1966, has been approved and has been implemented.

QA review of documents during the quarter placed particular emphasis on nondestructive testing requirements such as fluorescent dye penetrant inspection of turbine and boiler components to detect incipient cracking. Another area of major interest for QA reviewers was to check for details of suspected stress concentration with two purposes in mind; (1) to assure that dimensioning and tolerances are adequate, and (2) to provide special instructions to inspectors on the floor relative to those details.

Changes in procedure were effected to improve helium leak test performance. Detail method sheets were added to AGC-STD-1283 to specify the test set-up for each assembly to be tested such as TAA, MPMA, MIS, etc. These specific test procedures are utilized by technicians and inspectors.

The investigation of light-weight radiographic equipment to be used in test facilities; the equipment of four manufacturers were evaluated and NASA-LeRC and Atomics International were visited for the same purpose. Preliminary results indicate that gamma ray equipment utilizing Iridium 192 isotope as the source of radiation offers the optimum handling characteristics but does not provide sufficient resolution to allow judgement of weld quality to existing SNAP-8 requirements.

Nondestructive test equipment for measuring local mercury erosion of boiler tubes was under investigation. An attempt was made to utilize ultrasonic equipment available on the market; specifically, Magnaflux Corp. and Branson Instruments equipment was tried without success. A proposal to modify the existing Vidigage amplifier unit and to develop a special transducer for use inside the boiler tubes. This proposal is under review prior to release of the work authorization. In addition, work was initiated on the development of an air gage probe by the Sheffield Corp. that would measure oval or irregular tube erosion conditions, and a mechanical inside micrometer was procured that can be used up to 26 inches from the end of the tube.

Leak testing of TAA 6/2 was performed in accordance with the recently released helium leak test standard methods. QA representatives visited the supplier of new turbine nozzles to check and approve the optical comparator template that will be used for the control of EDM electrode contour. The template (T-258306) was checked under 100X magnification and found to be within 0.0005 in. of drawing requirements. Similarly, the optical comparator template for turbine wheel blades was inspected and approved. A problem was encountered with the 19-9DL material ordered per AMS-5526 due to excessive internal discontinuities. Ultrasonic inspection, not required by AMS-5526, will be performed on the material and added to the drawing requirements.

A quality engineering instruction was issued to the supplier of the composite turbine housing (P/N 092050-1), the MPMA induction motors (P/N 092684) and the TCV (AGC 10424), relative to the application of NPC 200-3 inspection system requirements to this specific hardware item.

NaK PMA thrust- and journal-bearing orders were accompanied by quality engineering instructions that provided specific requirements for the supplier's quality control efforts without formally involving NPC 200-3. This arrangement was selected to avoid additional supplier charges. Major QA efforts were made to upgrade the fabrication and inspection instructions for stator winding, potting, and PMA assembly. The applicable specifications were revised and issued.

Tube-in-shell boiler (P/N 092592-1) was shipped to NASA-LeRC with build-up and assembly log 1085. Inspection of the T-T boiler returned from NASA-LeRC followed the previous pattern of fluorescent dye penetrant checking of weld areas and radiographic inspection of tube wall thickness dimensions. This latter method yields data accurate to about 0.005 in. The certification of 9M-to-9M automatic weld joints is still in process. Inspection instructions were issued for tantalum lined tubing, tantalum plug inserts, and turbulator wire controls.

2. Quality Data and Corrective Action

During the reporting period, QA continued the release of monthly quality reports, consisting of summary inspection data, descriptions of nonconformances and corrective actions reported, and a classification of the causes of nonconformances (Figures V-24 and V-25, and Table V-3).

Formal corrective action requests were issued to suppliers in 27 cases of nonconformances, while 15 in-plant corrective action requests were directed toward fabrication problems.

The certification of SNAP-8 welders per AGC 14067 was upgraded to provide a qualification joint which closely simulates the boiler automatic weld joints. AGC and supplier welders will be required to pass the rigid qualification tests of AGC 14067 prior to the welding of the boiler replaceable plug sections.

A quality system audit was performed to check compliance with the requirements for the control of procured materials. Audit report 306 was issued, listing the deficiencies found and the proposed corrective action.

A second quality audit, involving the reinspection of accepted hardware, is still in process.

F. SPECIFICATIONS AND STANDARDS (1040-05)

1. Management and Planning

A new series of numbers has been assigned to the PCS prototype component specifications and the title of each of these specifications will include the word prototype.

In order to improve the efficiency and shorten the time required for specification review, an outline and "boiler plate" requirements for the component specifications were coordinated with cognizant personnel. This outline is consistent with the requirement of the NASA Apollo configuration management manual NPC-500-1 and Supplement 1.

REFERENCES

1. E. L. Wilson, A Digital Computer Program for the Finite Element Analysis of Solids with Nonlinear Material Properties, Technical Memorandum No. 23, Aerojet-General Corp., Sacramento, July 1965.

2. L. R. Hermann, A Bending Analysis for Plates, Technical Paper No. 7, SRO, Aerojet-General Corp., Sacramento, March 1965.

3. F. E. Peterson, User's Supplement for the Finite Element Analysis of Solids with Nonlinear Material Properties, Aerojet-General Corp., Sacramento, March 1966.

4. SNAP-8 Electrical Generating System Development Program, Quarterly Progress Report No. 3297 for July - September 1966, Aerojet-General Corp., Azusa, November 1966.

5. C. L. Foss, Lubrication and Cooling System for the Hg PMA, Test Report - GN_2S-1 Test Loop, Technical Memorandum 4932:66-402, Aerojet-General Corp., Azusa, February 1967.

6. N. E. Waldschmidt, Alternate Circuits for Improving the Operating Characteristics of the SNAP-8 Speed Controller, Especially Outside the Normal Control Region, Technical Memorandum 4936:67-447, Aerojet-General Corp., Azusa, January 1967.

7. N. Van De Verg, Some Performance Calculations for a Dual PCS SNAP-8 EGS, Technical Memorandum 4921:66-446, Aerojet-General Corp., Azusa, February 1967.

8. R. G. Geimer, N. Van De Verg, and L. P. Lopez, Analysis of SNAP-8 Performance with 1200°F Reactor Temperature, Technical Memorandum 4922:66-416, Aerojet-General Corp., Azusa, July 1966.

9. SNAP-8 Electrical Generating System Development Program, Monthly Progress Report No. L0740-05-18, Aerojet-General Corp., Azusa, June 1966.

10. SNAP-8 Materials Report for July - December 1966, Report No. 3349, Aerojet-General Corp., Azusa, January 1967.

11. W. V. Mackewicz, and D. Yee, Small-Scale Boiler Phenomena Studies for SNAP-8 Continuation Program, Technical Memorandum AN-SNAP-66-284, Aerojet-General Nucleonics, June 1966.

12. A. J. Sellers, SNAP-8 Tube-in-Tube Boiler Design Analysis, Technical Memorandum 4803:65-2-223, Aerojet-General Corp., Azusa, February 1965.

13. B. L. Amstadter, Evaluation of Data from PCS-1, Phase IV, Step 2 Testing Using Analysis of Variance with Enumeration of the General Advantages of this Method, Technical Memorandum 4925:66-401, Aerojet-General Corp., Azusa, November 1966.

TABLE V-1

SUGGESTED OPERATING CONDITIONS FOR SYSTEM WITH NOMINAL 1200°F REACTOR OUTLET TEMPERATURE

$\dot{W}_{Pri}$	=	49,000 lb/hr	(No change)
$\dot{W}_{HgL}$	=	9200 lb/hr	(Reduced to meet ΔTpp requirement)
$\dot{W}_{HRL}$	=	28,000 lb/hr	(Reduced to meet ΔT and Q values)
P_{Tin}	=	176 psia	(Reduced since $\dot{W}_{Hg}$ is reduced)
T_{Tin}	=	1145°F (min)	(Results of decreased reactor temp.)
P_{Tout}	=	10 psia	(Reduced from 14 psia)
$P_{cond_{in}}$	=	9.5 psia	(Reduced from 13.5 psia)
$T_{Hg_{CI}}$	=	632°F	(Reduced in accordance with P_{cond})
$\Delta T_{T_{Boil}}$	=	20°F	(No change)
ΔTpp	=	30°F	(No change)
Carryover	=	2%	(Reduced since $\dot{W}_{Hg}$ is reduced)
πT	=	0.56	(No change)
P_{Net}	=	20.8 kw	
p.f.	=	1.0	
Kn	=	2050	(No change)

TABLE V - 2

4925-67-0002

CUMULATIVE OPERATING TIMES FOR MAJOR PCS COMPONENTS THROUGH 31 DECEMBER 1966

Component	Through 11-30-66		12/1-12/31/66 Inclusive		Cumulative to 1-1-67		Remarks/Status
	Cum Hours	Cum Starts	Op. Hours	No. Starts	Cum Hours	Cum Starts	
1. TAA							
Unit 1/4, S/N A-4	0	0	0	0	0	0	Installed 10-24-66 in PCS-1, Step 3.
Unit 3/2, S/N A-3	820	47	0	0	820	47	Single unit maximum operating time.
Total all units	1287	134	0	0	1287	134	Total 6 units tested.
2. NaK PMA							
Unit 1/4, S/N A-5	581	52	0	0	581	52	Repaired and reinstalled in LNL-3 on 12-28-66.
Unit 5/3, S/N A-6	134	16	52	93	186	109	PCS-1, HR Loop, Start test.
Unit 6/3, S/N A-7	254	12	50	60	304	72	PCS-1, PN Loop, Start test.
Unit 1/2, S/N A-5	3028	--	--	--	3028	--	Single unit maximum operating time (See Unit 1/4, 3028 hrs + 581 = 3609 hrs.)
Total all units	5700	992	102	153	5802	1145	Total 10 units tested.
3. Hg PMA							
Unit 4/2, S/N A-2	180	16	0	0	180	16	PCS-1, Step 3 (Unit 4/1 decontaminated).
Unit 2, S/N A-1	1099	--	0	0	1099	--	Single unit maximum operating time.
Total all units	2155	--	0	0	2155	--	Total 5 units tested. No operating time this month.
4. L/C PMA							
Unit 7/1, S/N 481507	307	28	101	46	408	74	PCS-1, Step 3, Start test.
Unit 1/2, S/N 481501	1260	316	0	0	1260	316	LNL-3 7000 hr. endurance testing.
Unit 1, S/N 481501	4552	--	0	0	4552	--	Single unit maximum operating time.
Total all units	9058	--	101	46	9159	--	Total 5 units tested.
5. Boiler							
T-T Unit 2, S/N 481600	587	--	0	--	587	--	Removed 8-66. Single unit maximum operating time (PCS-1, Ph IV).
T-T Total	1117	--	0	--	1117	--	2 units tested.
T-S Total	1655	--	0	--	1655	--	2 units tested. Single unit time 1429 hrs (RPL-2).
Total all units	2772	--	0	--	2772	--	Total 4 units tested. No operation this month.
6. Condenser							
Unit No. 2, S/N A-2	2016	--	0	0	2016	--	PCS-1, Ph IV. Single unit maximum operating time.
Total all units	2772	--	0	0	2772	--	2 units tested.
7. Auxiliary Start Heat Exchanger							
Unit No. 3, S/N A-1	254	12	50	60	304	72	PCS-1, Step 3.
Unit No. 2, S/N A-3	1177	724	0	0	1177	724	LNL-3 (NaK Loop flow time).
Unit No. 1	1243	--	--	--	1243	--	Single unit maximum operating time (RPL-2).
Total all units	2285	736	50	60	2335	796	Total 4 units tested.
8. Parasitic Load Resistor							
Unit No. 2, S/N A-2	480	16	52	93	532	109	PCS-1, HR Loop, Start test.
Unit No. 3, S/N A-1	1177	724	0	0	1177	724	LNL-3.
Total all units	1268	711	52	93	1320	804	2 units tested.
9. Inverter							
Unit No. 1, S/N 926460	107	130	.2	5	107	135	Moved from LNL-3 to PCS-1, Step 3.
Unit No. 2, S/N 926461	0	0	3.0	17	3	17	Removed 12-22-66, F.R. No. 0337.
Total all units	107	130	3.0	22	110	155	Total 2 units tested.

TABLE V-3

CLASSIFICATION OF THE CAUSES OF NONCONFORMANCES

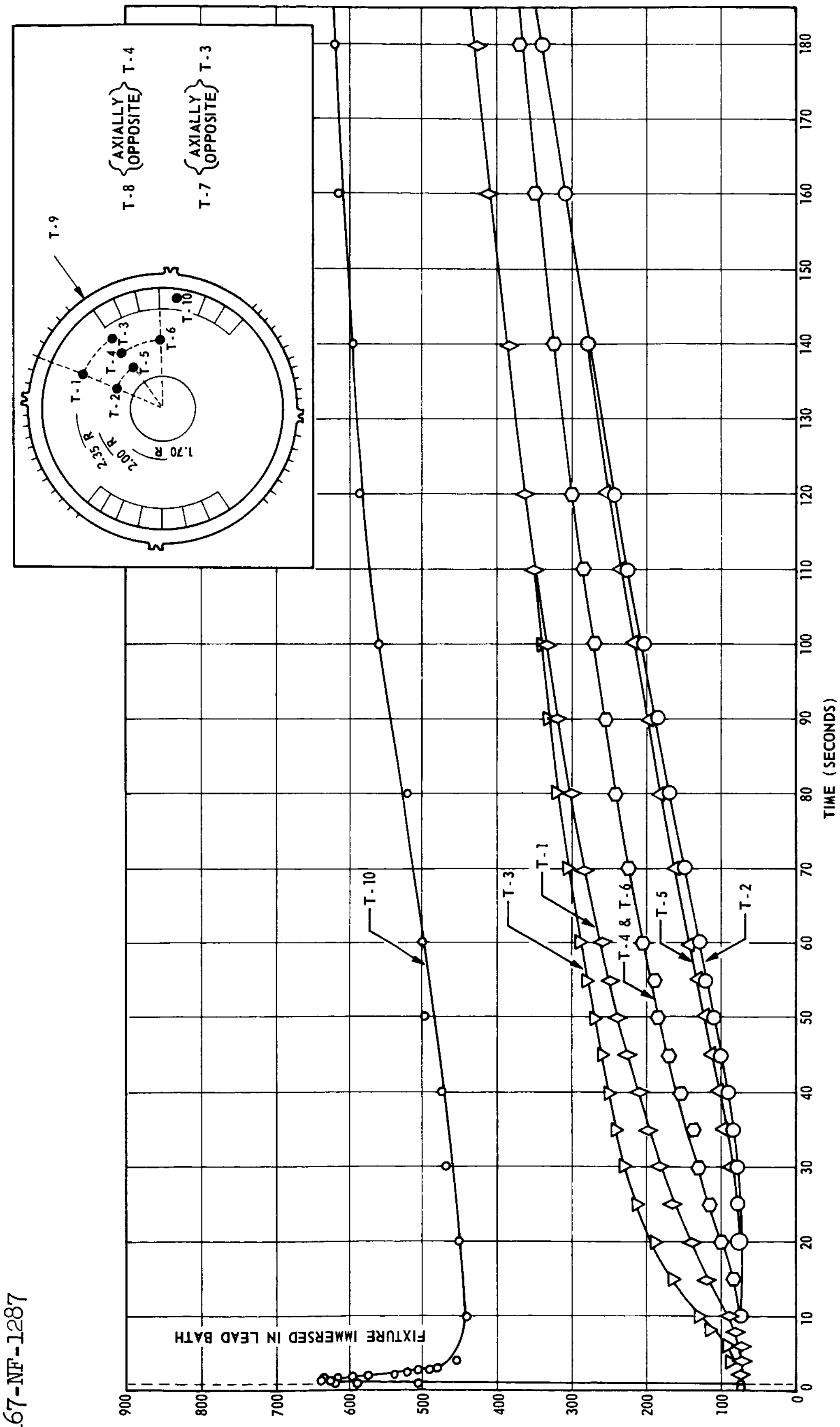
November 1966

No. of Occurrences * November	FY 1967 Cum.		Description
2	7	A.	Operator Errors or Shop Problems Operator misunderstood instructions, made errors.
2	5	B.	Wormanship Problems Hardware did not meet workmanship standards.
4	11	C.	Tooling or Equipment Problems Nonconformance was caused by inadequate, or insufficient tooling or equipment.
0	9	D.	Handling or Environmental Damage, Inadequate Special Process Controls Examples: Corrosion, physical damage, failure in leak testing.
6	17	E.	Planning or Change Control Problems Inadequate, incorrect, out-of-date instructions.
1	11	F.	Engineering Problems Nonconformances attributed to engineering problems as reflected in drawing and specification requirements.
1	25	G.	Nonconformance of Supplier Furnished Material The responsibility for the nonconformance rests with a supplier.
5	15	H.	Procedural or Paperwork Problems Evidence of inspection missing, required documentation lacking, etc.

TABLE V-3 (cont.)

No. of Occurences *			Description
November	FY 1967 Cum.		
1	14	I.	Nonconformance Caused by Operational Degradation Defects attributed to degradation during functional use or testing.
5	22	J.	Miscellaneous, Undetermined, or Pending Investigation Self-explanatory

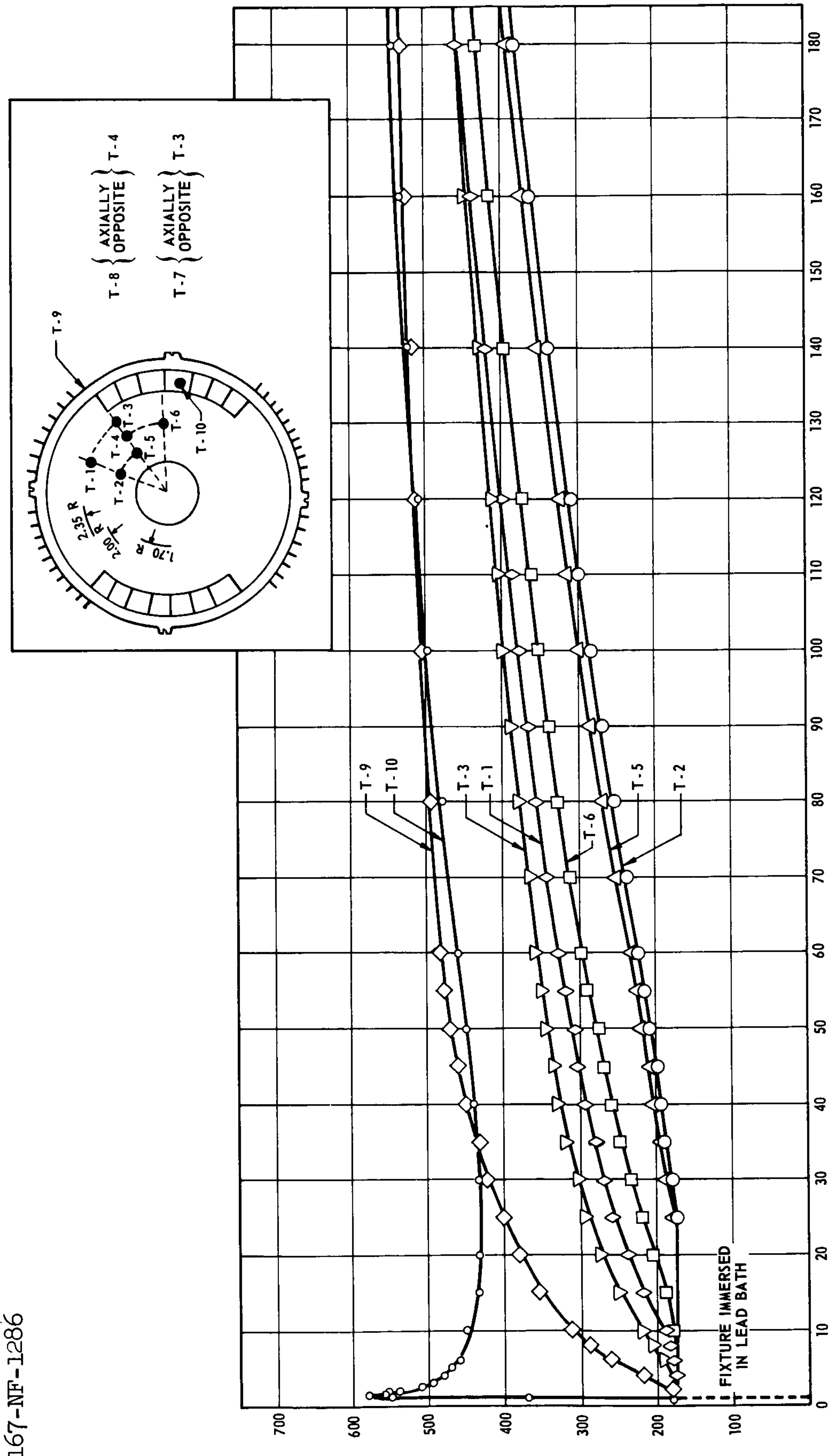
* The number of "occurrences" correlates with the number of incidents (problems) reported; it does not refer to hardware quantities.



Turbine Assembly Second-Stage Nozzle Diaphragm Thermal Shock Test
No Preheat and 700°F Lead Bath Temperature (P/N 095240-1)

167-NF-1287

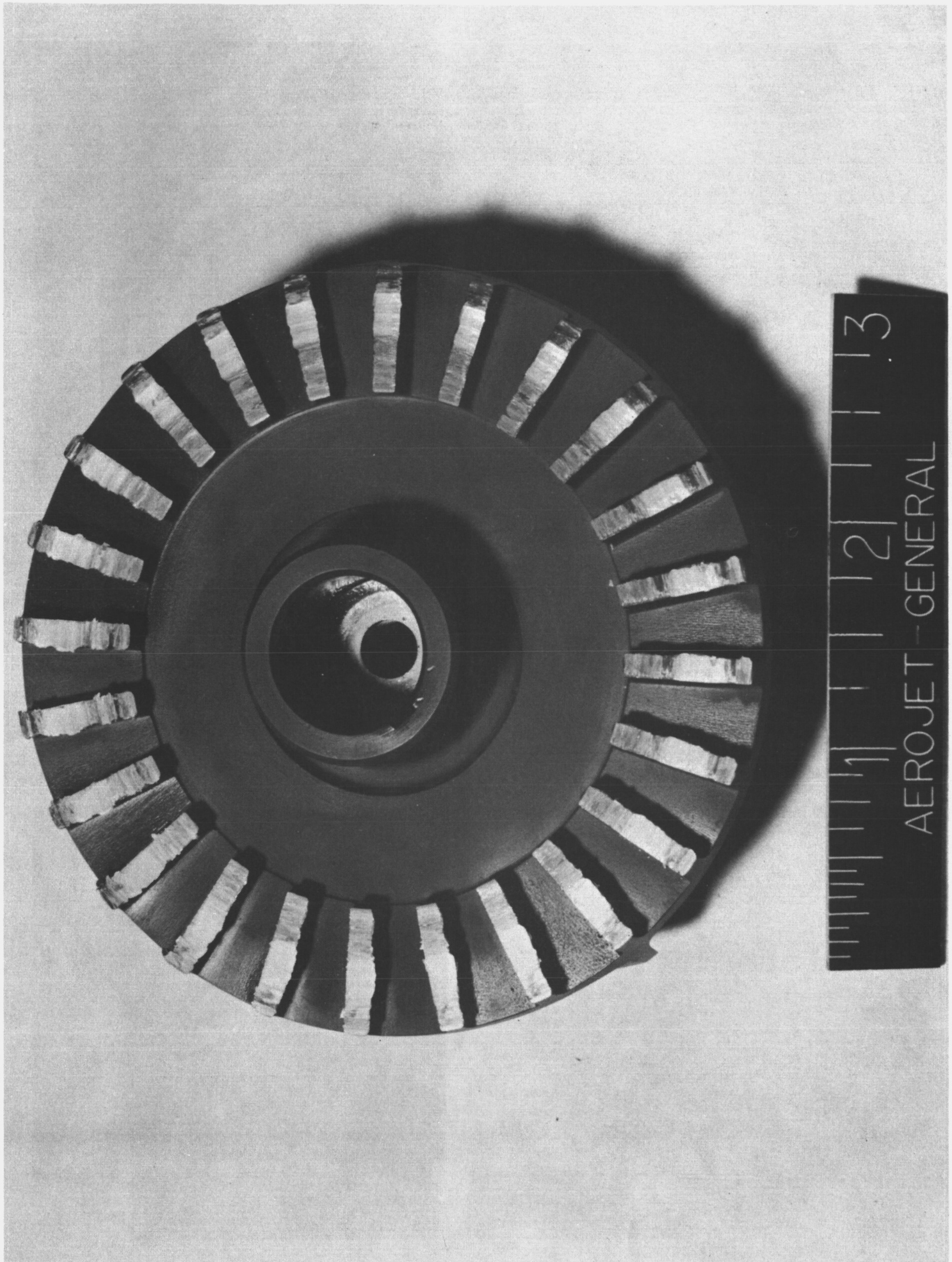
Figure II-1



Turbine Assembly Second-Stage Nozzle Diaphragm Thermal Shock Test
200°F Preheat and 700°F Lead Bath Temperature (P/N 095240-1)

167-NF-1286

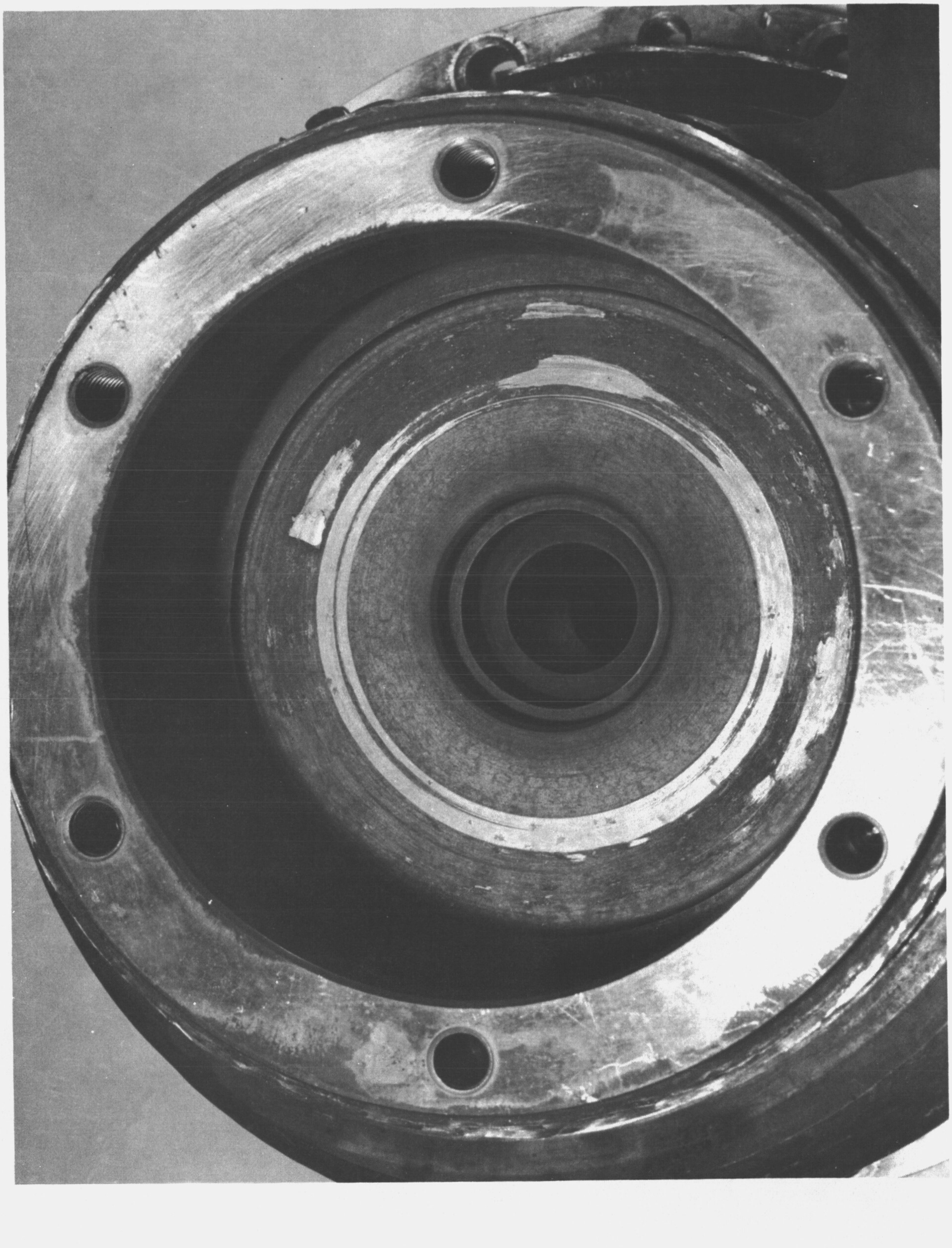
Figure II-2



NaK Pump-Motor Assembly Impeller Back Vanes (P/N 093510-1) Showing Rubbing from Operation in LNL-3 Unit 2/3 with 0.011 Backface Clearance

1066-637

Figure II-3



1066-631

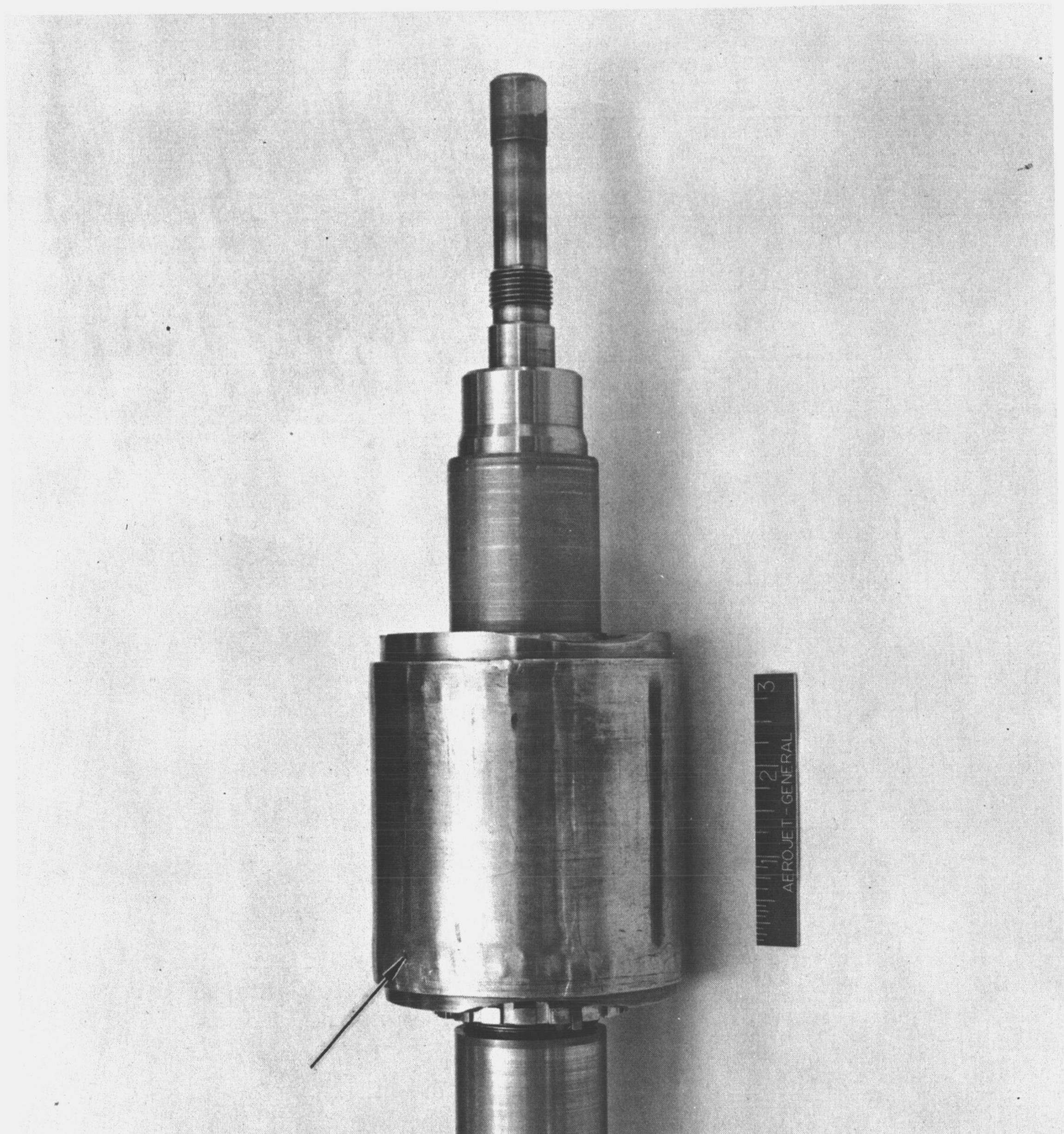
NaK Pump Housing (P/N 095660-1) LNL-3 Unit 2/3

Figure II-4

NaK Pump-Motor Stator Housing (P/N 092992-1) from LNL-3 Unit 2/3 - Recirculation Pump End

1066-633

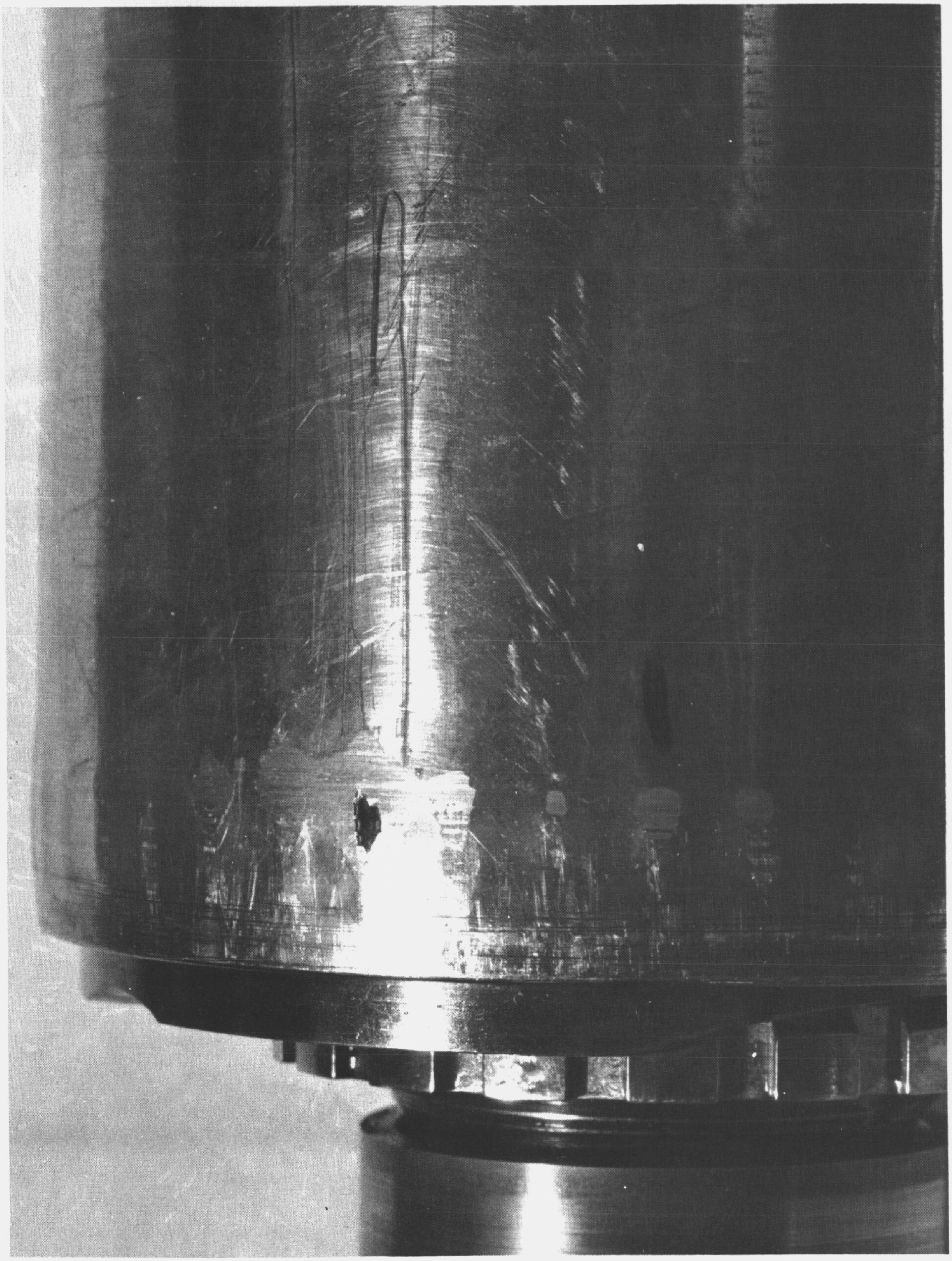
Figure II-5



NaK Pump-Motor Assembly Rotor (P/N 093202-1), from LNL-3 Unit 2/3
Showing Rub-through (Arrow)

1066-636

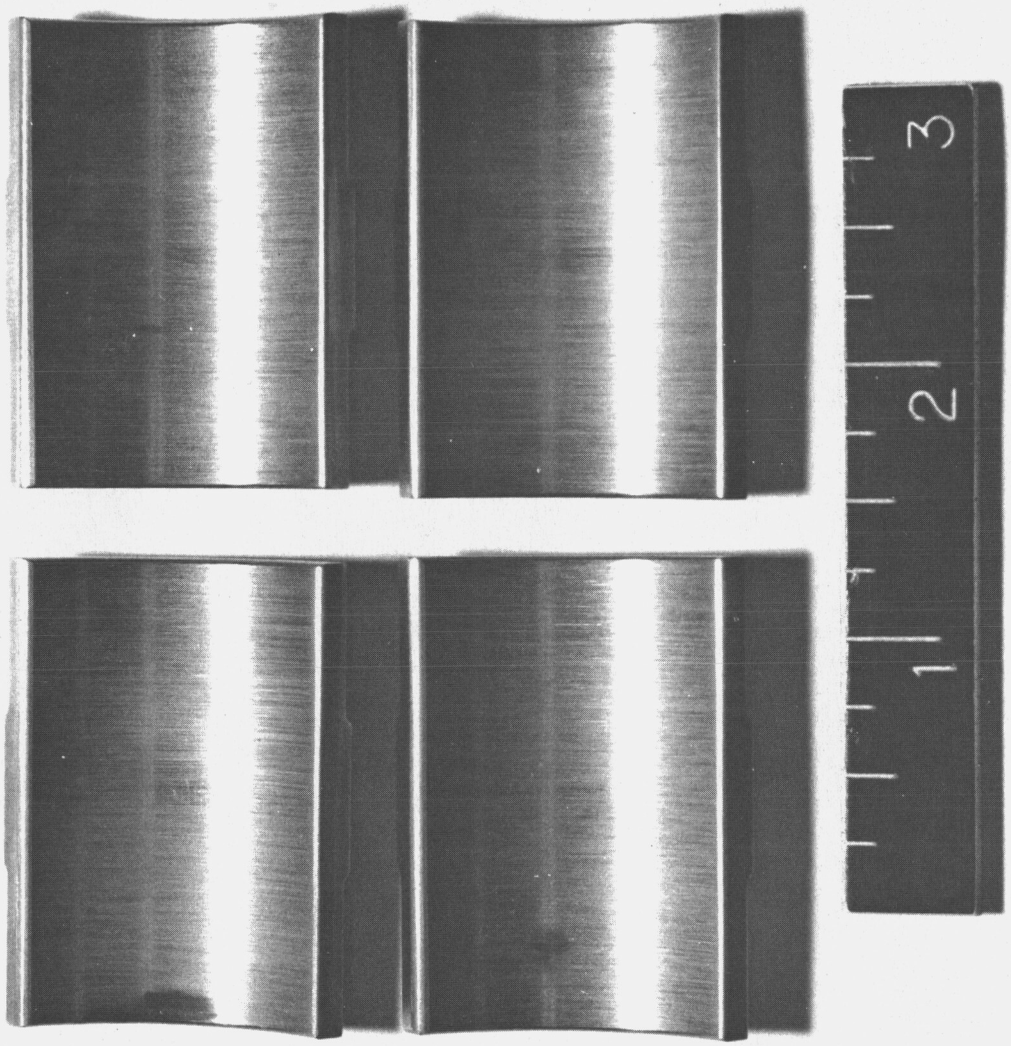
Figure II-6



1066-635

NaK PMA Rotor (P/N 093202-1), Close-up Recirculation Pump End Showing Rub-through Hole - From LNL-3 Unit 2/3

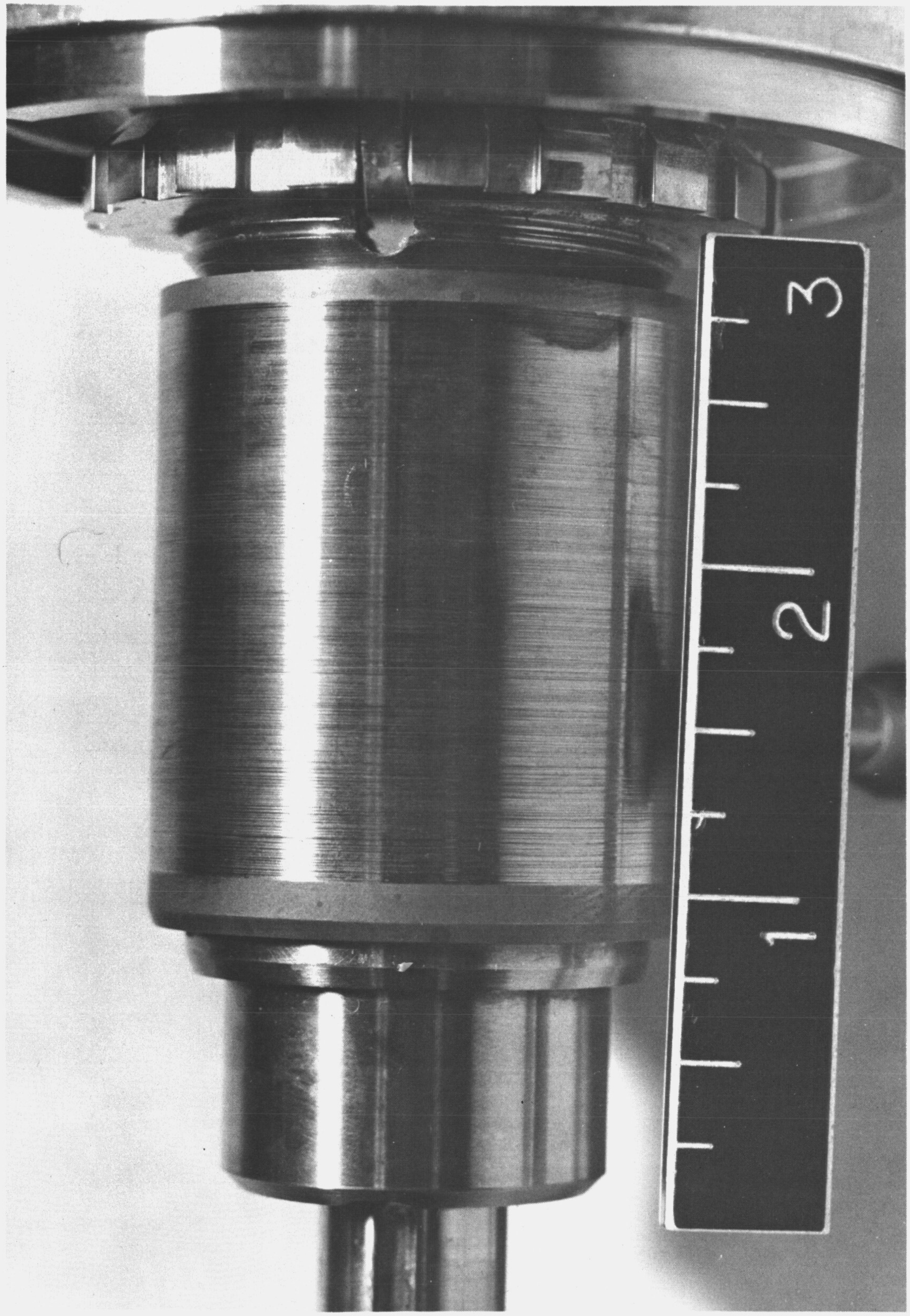
Figure II-7



NaK PMA Journal Bearing Pads Recirculation Pump End
Showing Fine Scratches - From LNL-3 Unit 1/3

1166-0849

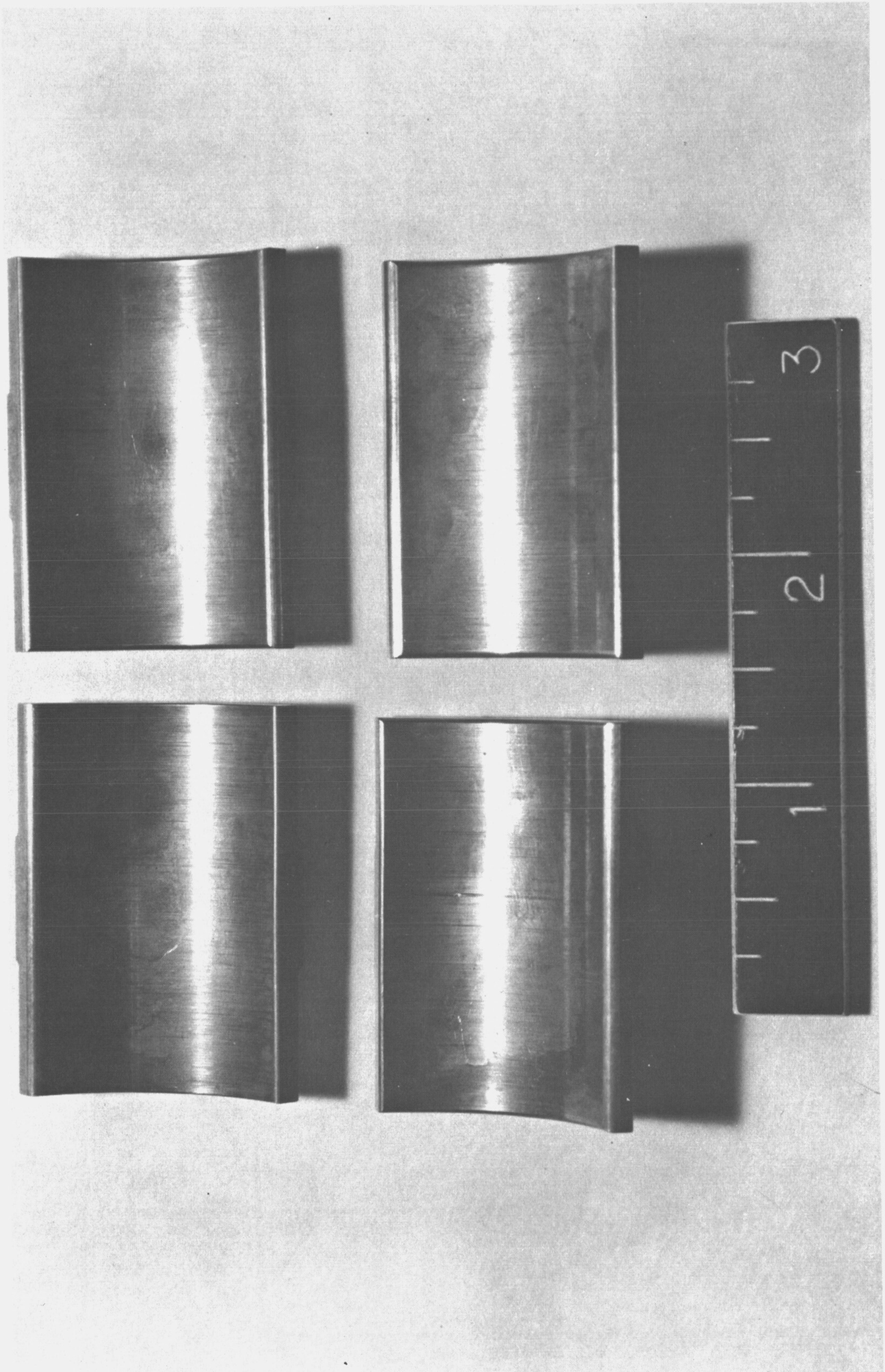
Figure II-8



NaK PMA Shaft Journal Sleeve, Recirculation Pump
End - From LNL-3 Unit 1/3

1166-0854

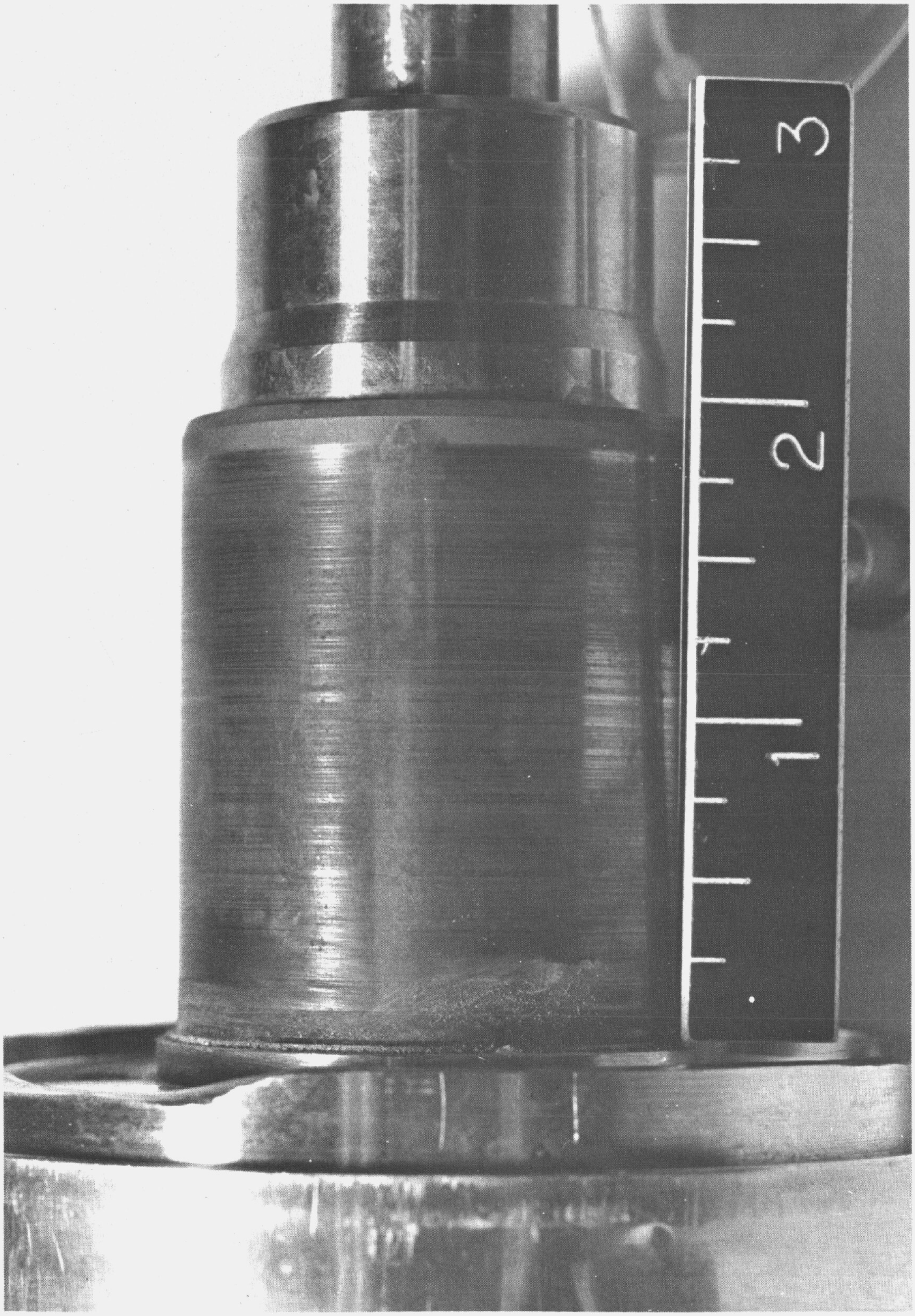
Figure II-9



NaK PMA Journal Bearing Pads, Pump End - LNL-3 Unit 1/3

1166-0848

Figure II-10



1166-0855

NaK PMA Shaft Journal Sleeve, Pump End - LNL-3 Unit 1/3

Figure II-11

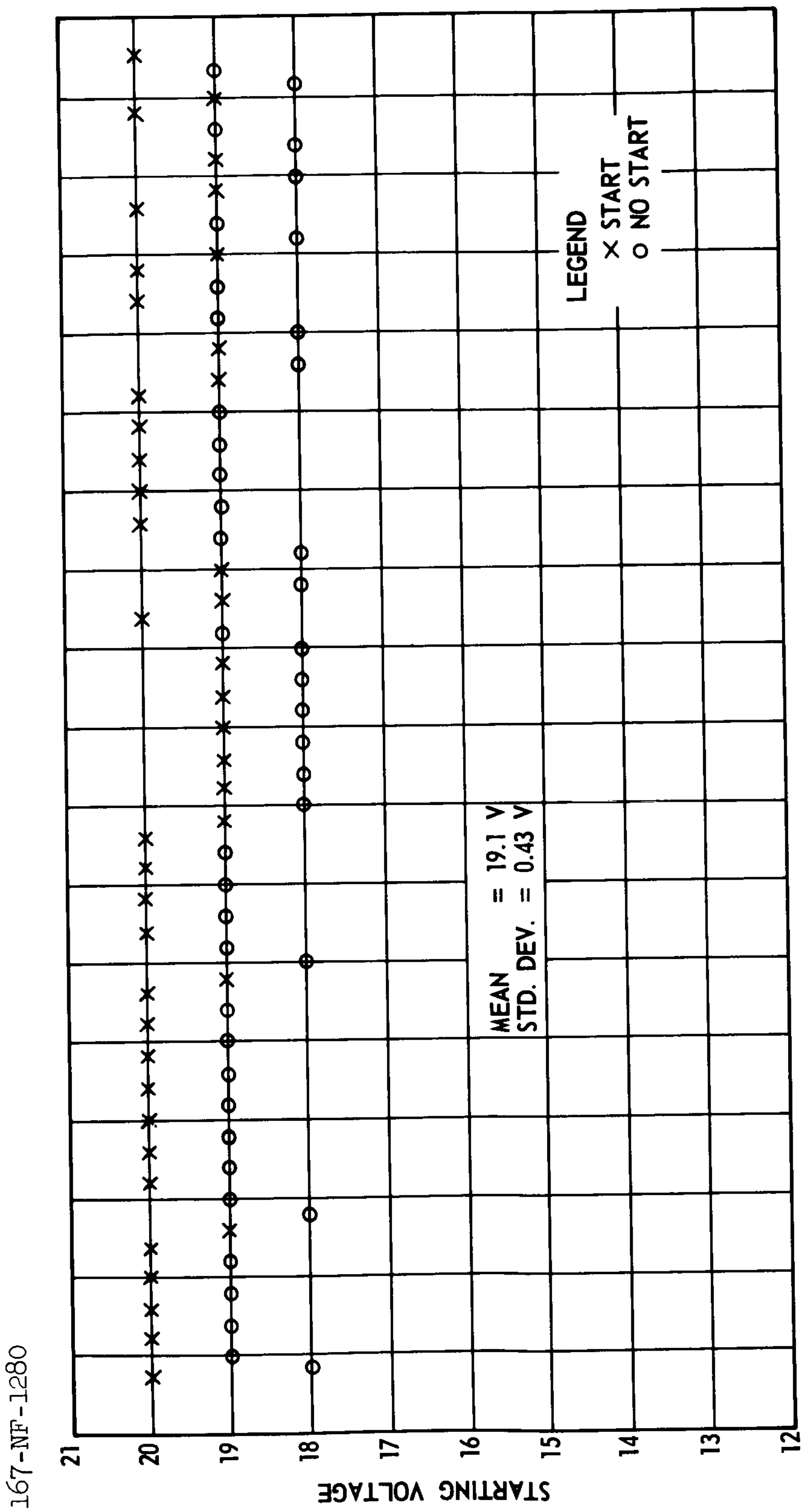
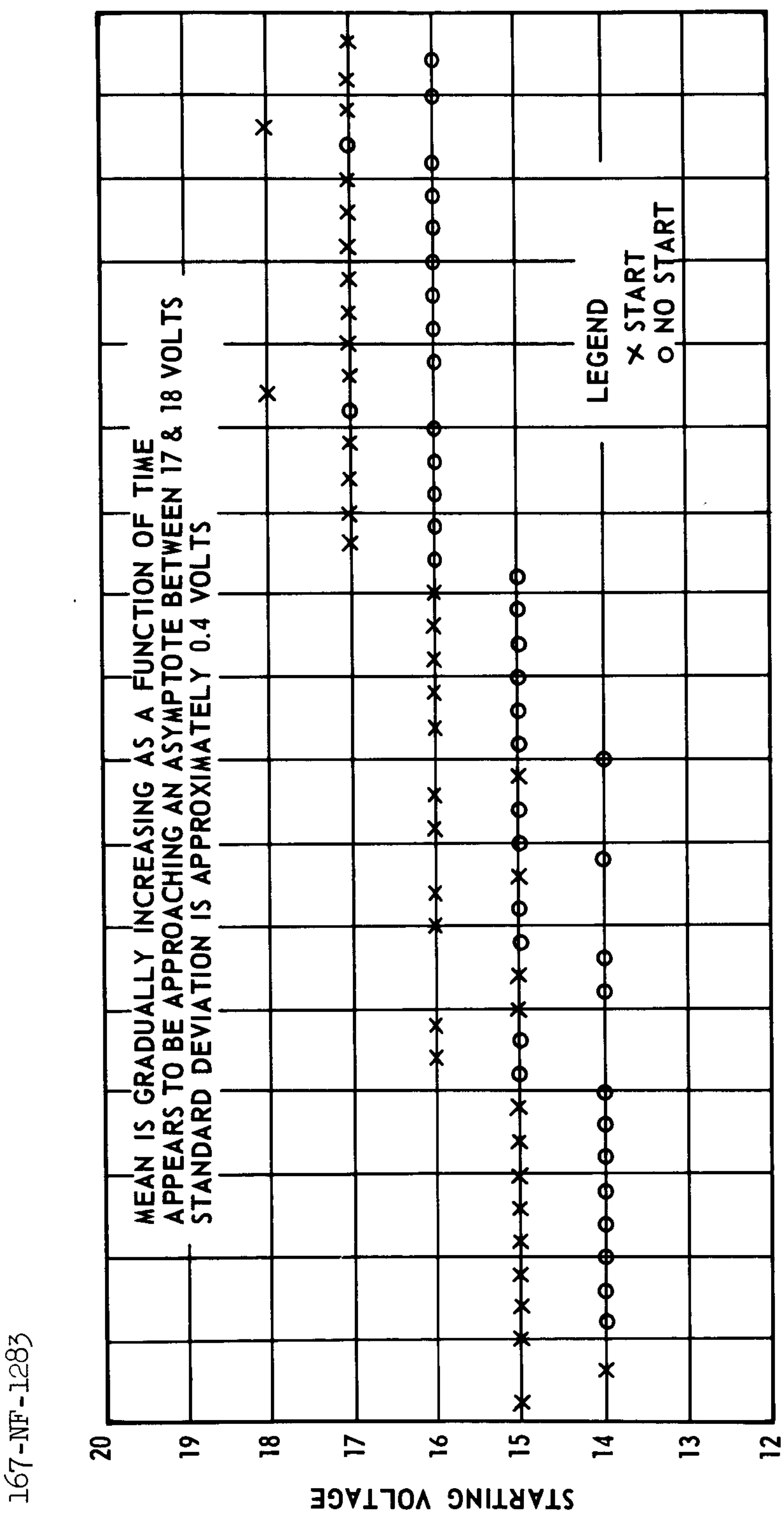

LEGEND
× START
o NO START
MEAN = 19.1 V
STD. DEV. = 0.43 V
21
20
19
18
17
16
15
14
13
12
STARTING VOLTAGE
167-NF-1280

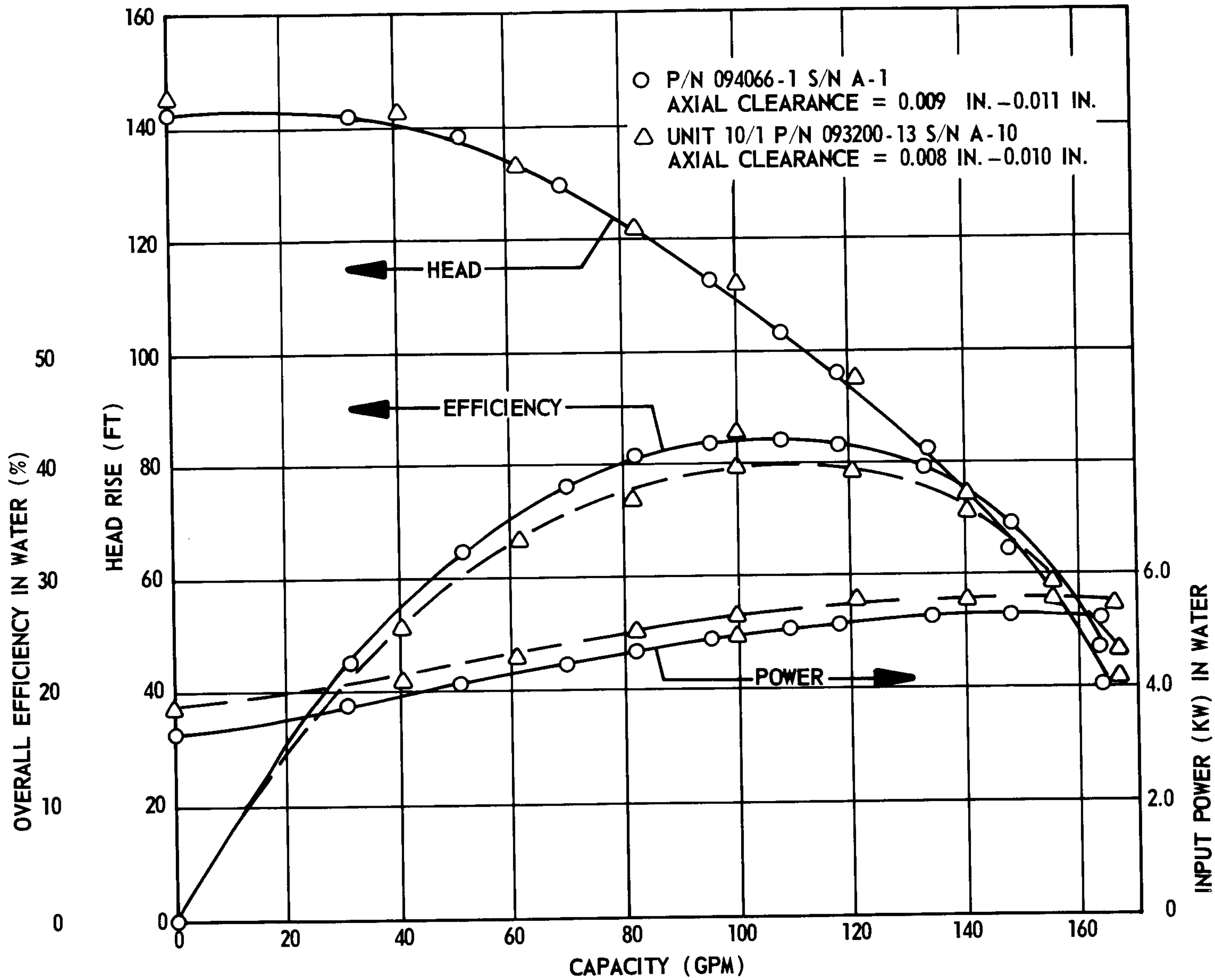
Figure II-12



Primary NaK PMA (S/N A-7) PCS-1 Phase IV Step 3 Minimum Voltage Start Test (12-20-66)

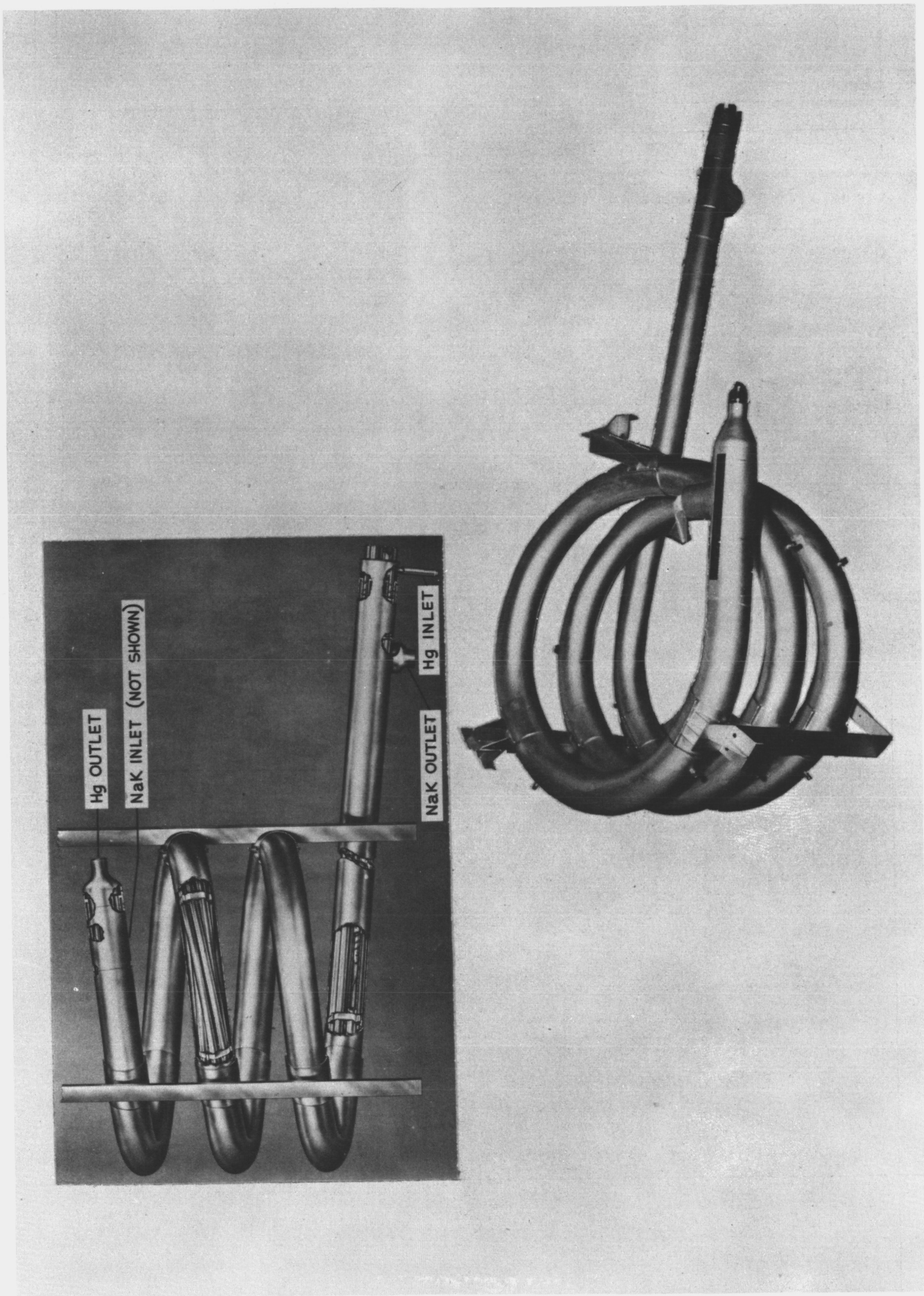
Figure II-13

167-NF-1288



Comparison of NaK PMA Performance Curves in Water (400cps)

Figure II-14

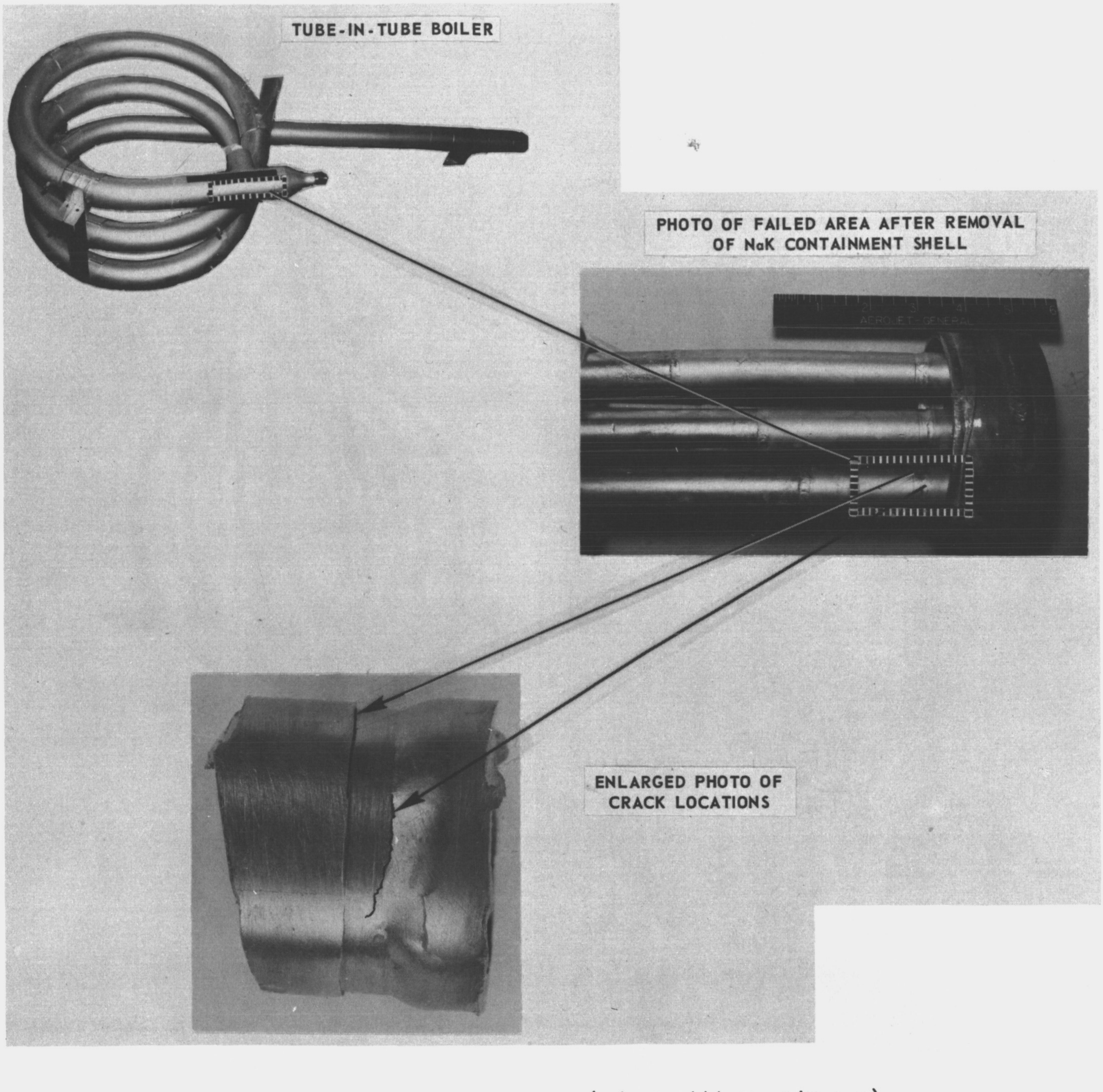


566-219

SNAP-8 Tube-in-Tube Boiler

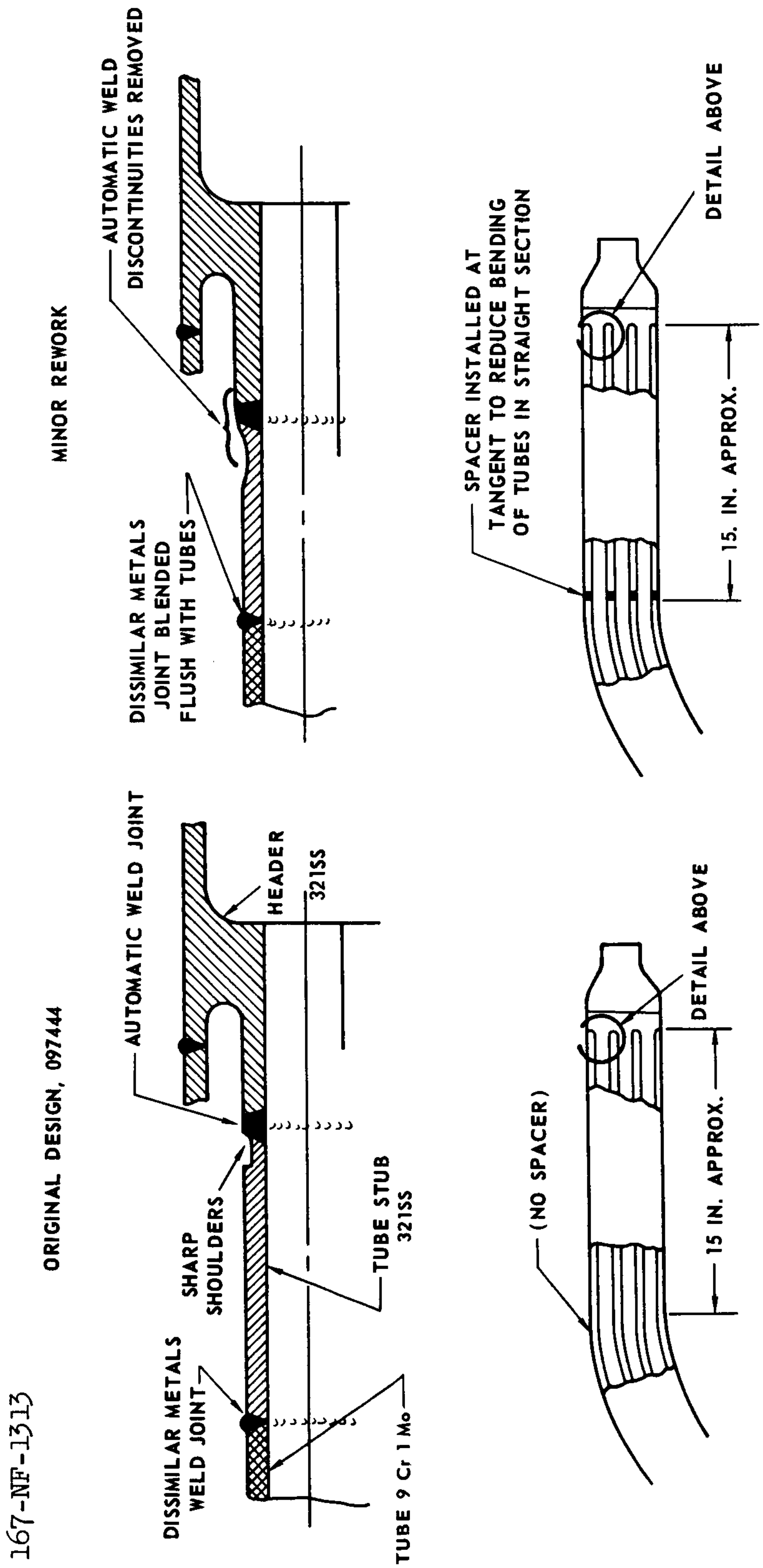
Figure II-15

167-NF-1310



Tube-in-Tube Boiler Failure (P/N 097444-7, S/N A-2)

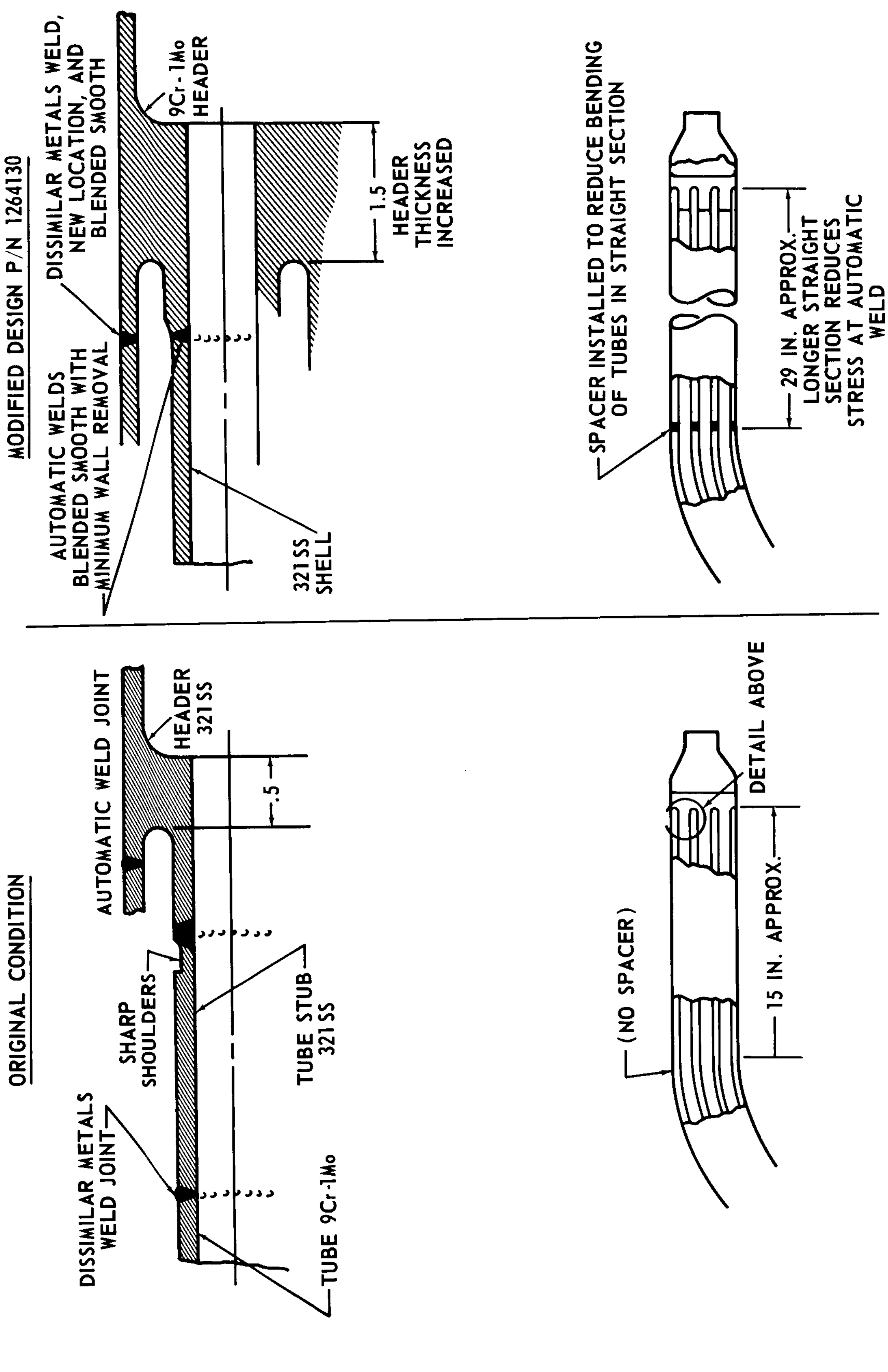
Figure II-16



Rework of Boiler No. 3 for Limited Service
(P/N 097444-31, S/N 481601)

Figure II-17

167-NF-1312



Incorporation of Stress Recommendations for Boiler Units 1 and 2

Figure II-18

167-NF-1285

SYMBOLS

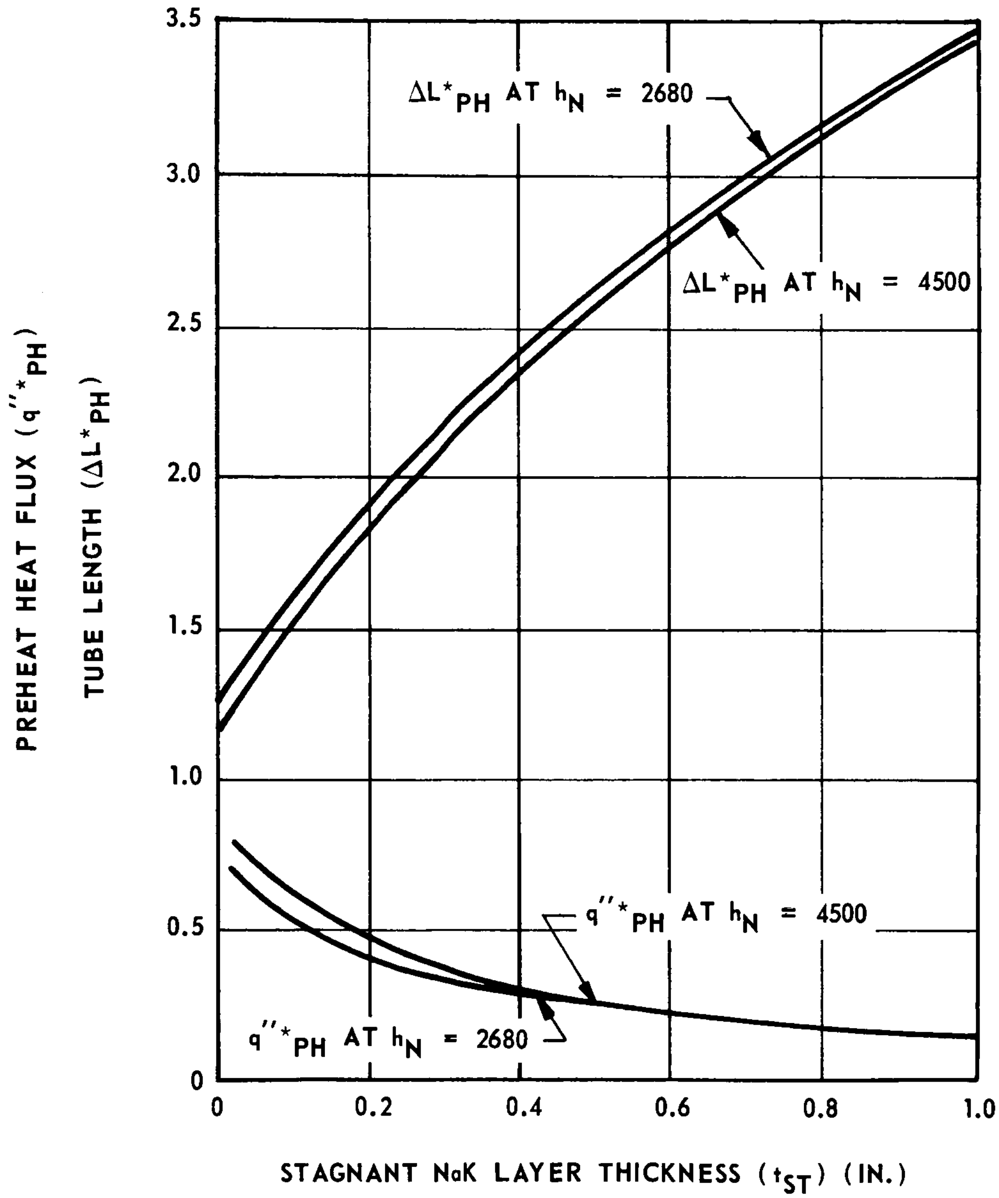
q'' – HEAT FLUX

ΔL – CHANGE IN LENGTH

h_N – NaK-SIDE FILM COEFFICIENT, BTU/HR-FT^2-°F

* – RELATIVE TO CURRENT DESIGN

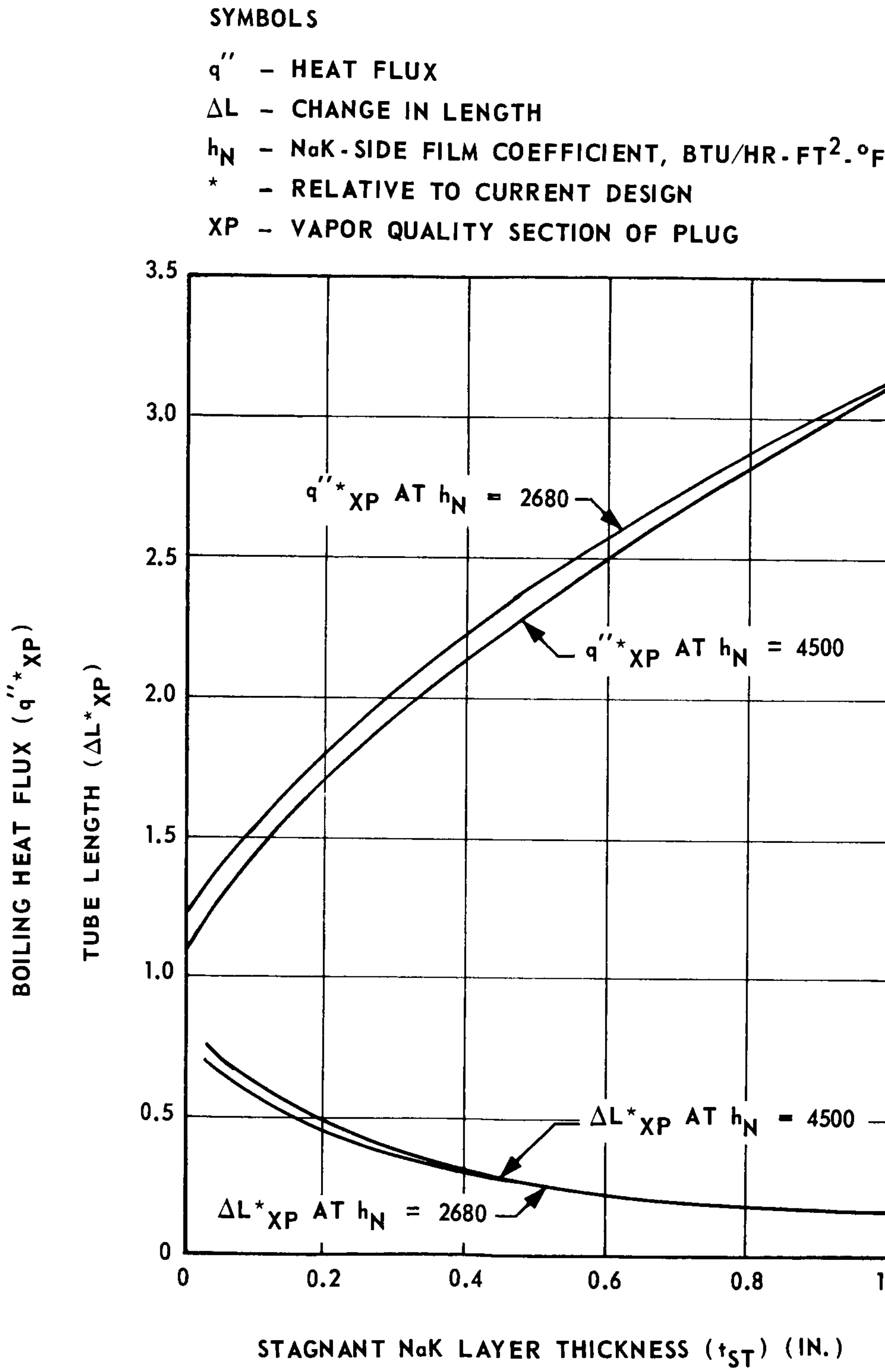
PH – PREHEAT PORTION OF BOILER



Double Containment Boiler Tube - Preheat Heat Flux and
Tube Length vs Stagnant NaK Layer Thickness

Figure II-19

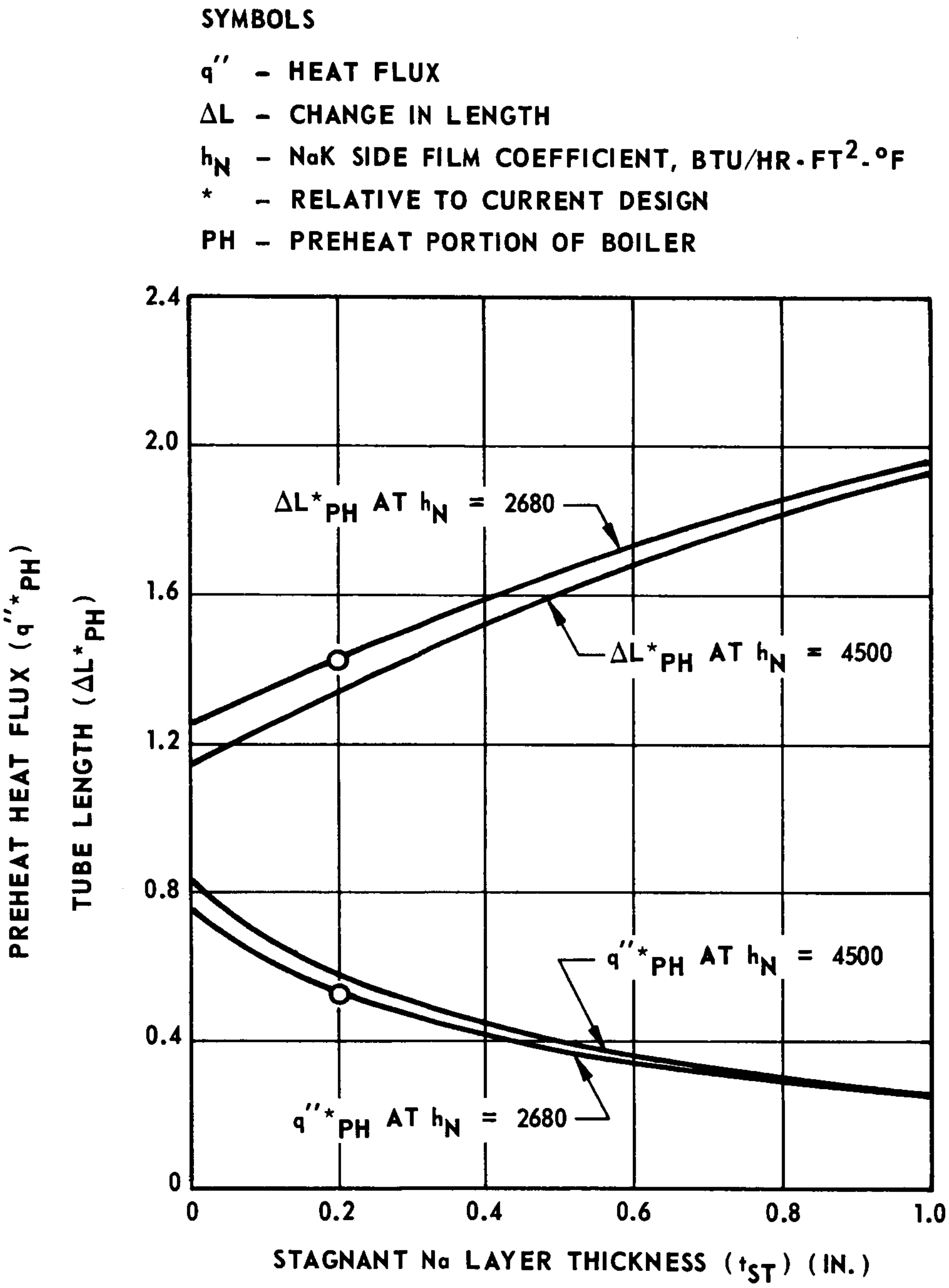
167-NF-1284



Double Containment Boiler Tube - Boiling Heat Flux and
Tube Length vs Stagnant NaK Layer Thickness

Figure II-20

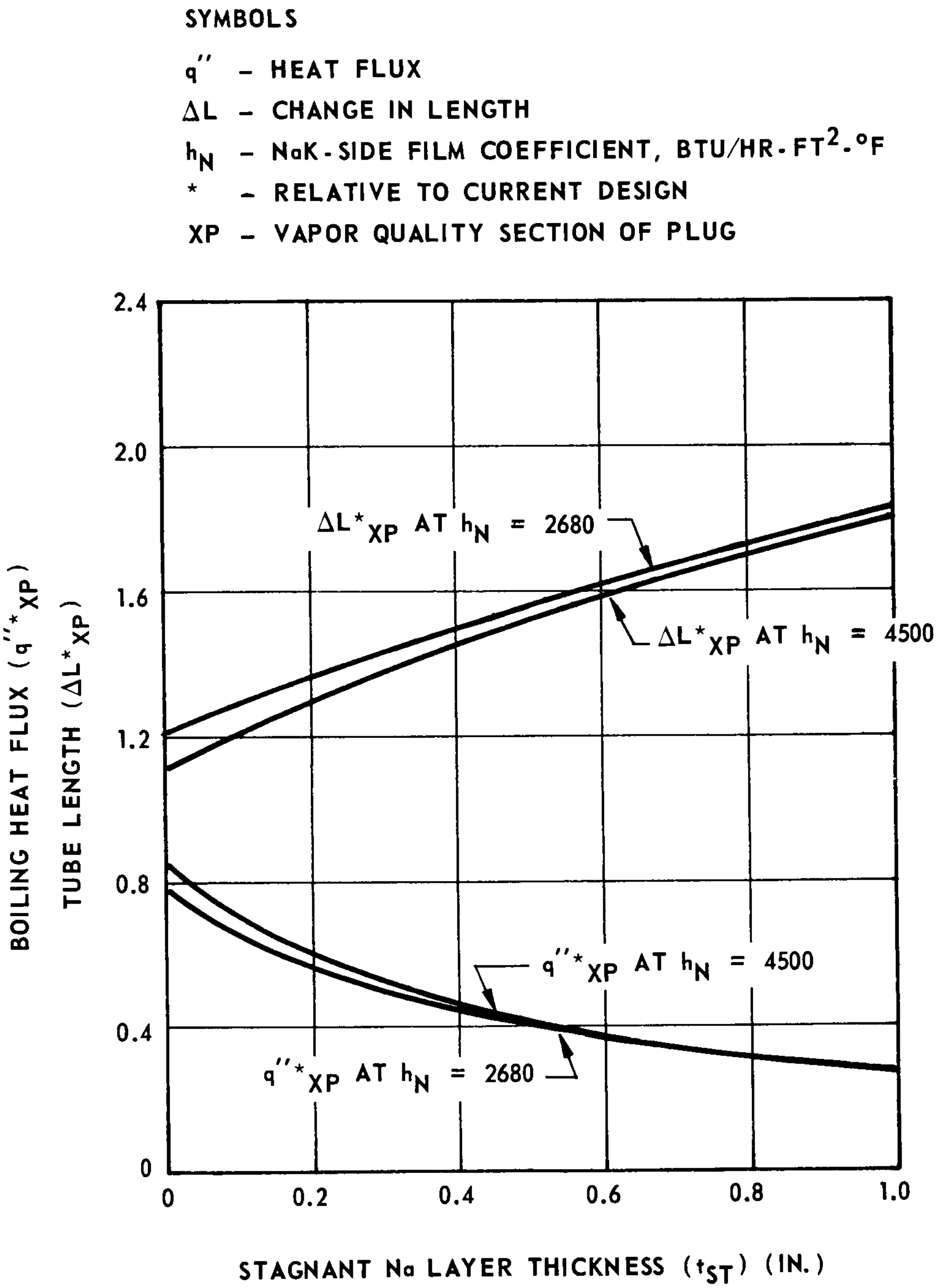
167-NF-1282



Double Containment Boiler Tube - Preheat Heat Flux and Tube Length vs Stagnant Na Layer Thickness

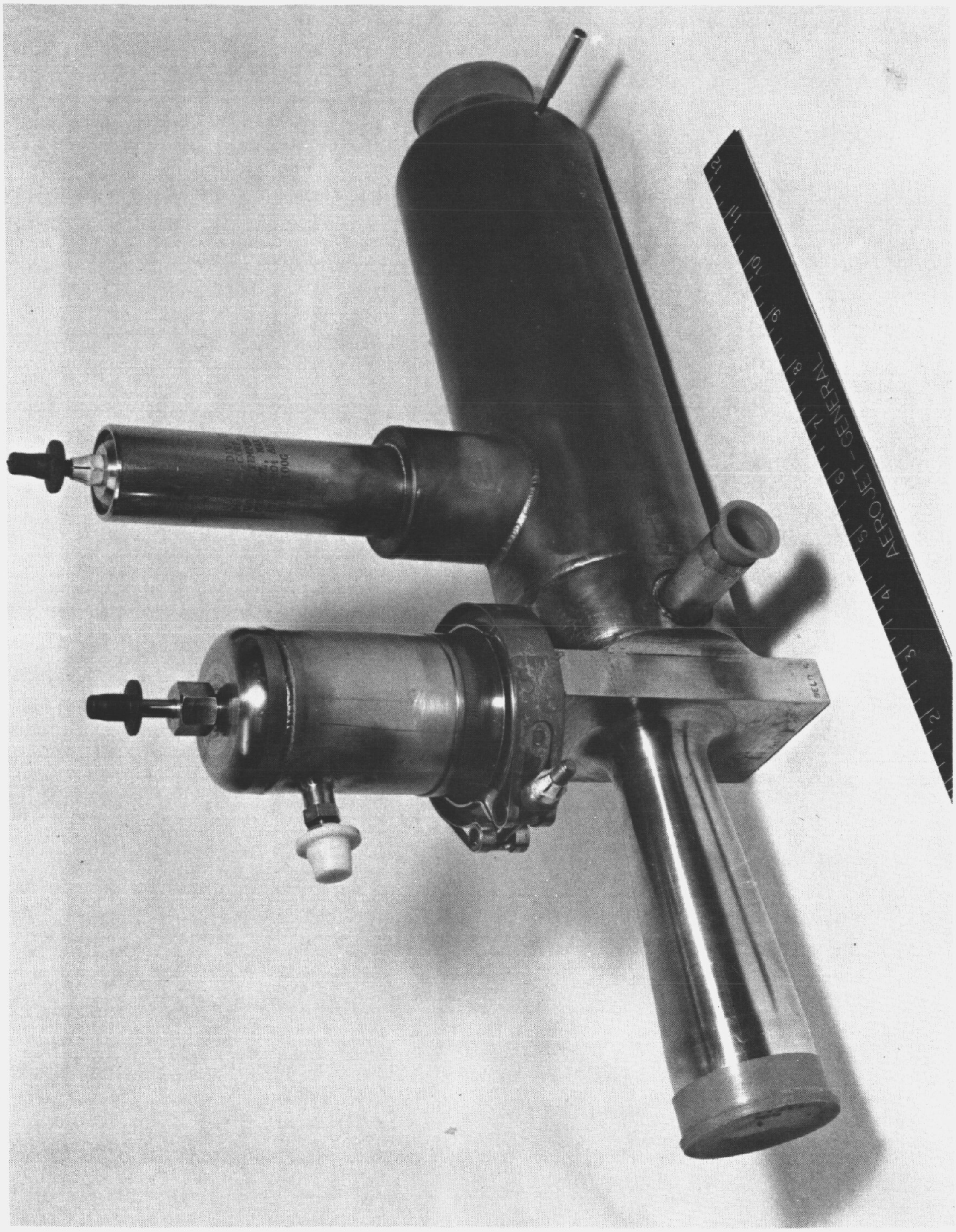
Figure II-21

167-NF-1281



Double Containment Boiler Tube - Boiling Heat Flux and Tube Length vs Stagnant Na Layer Thickness

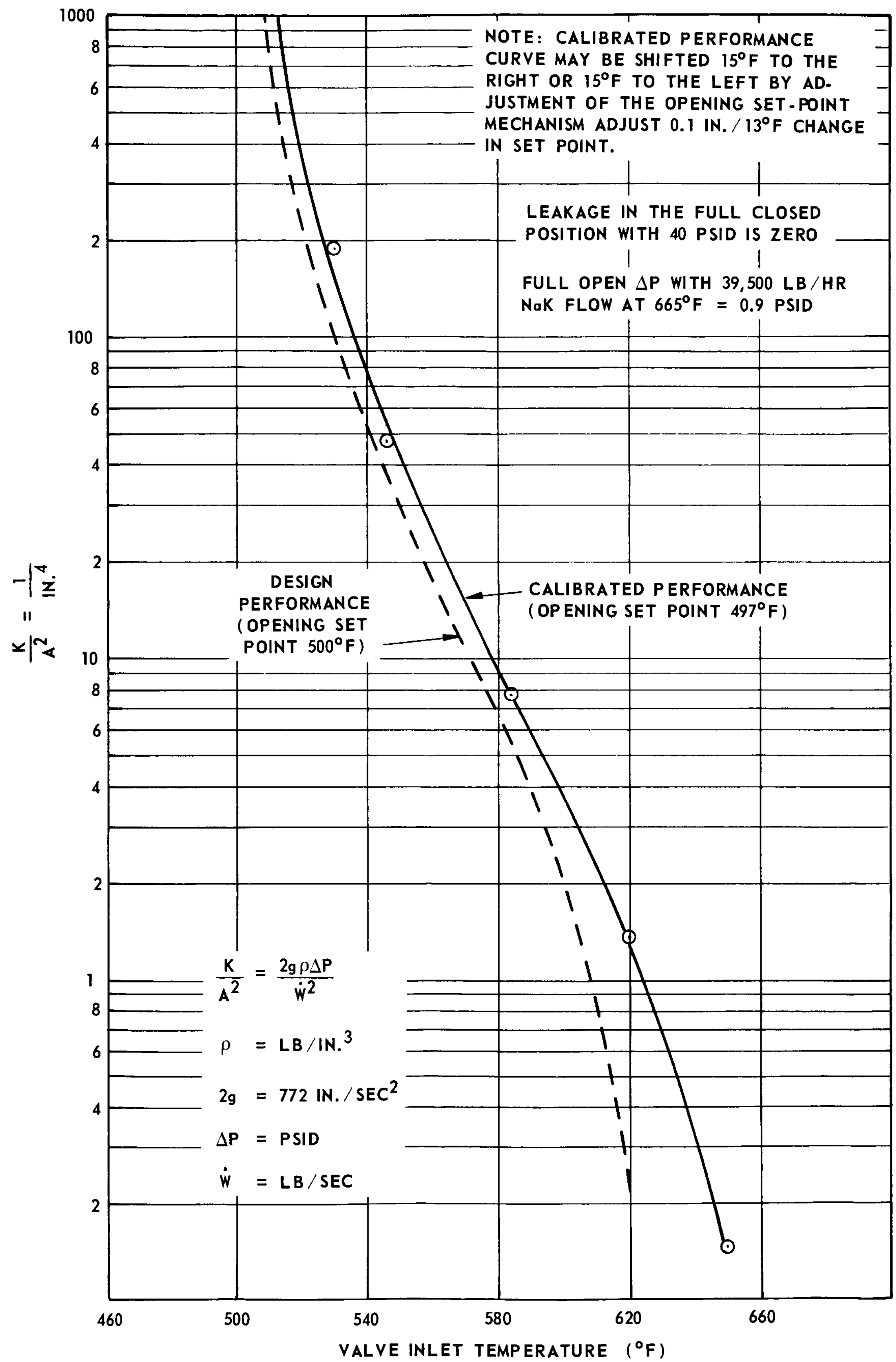
Figure II-22



466-098

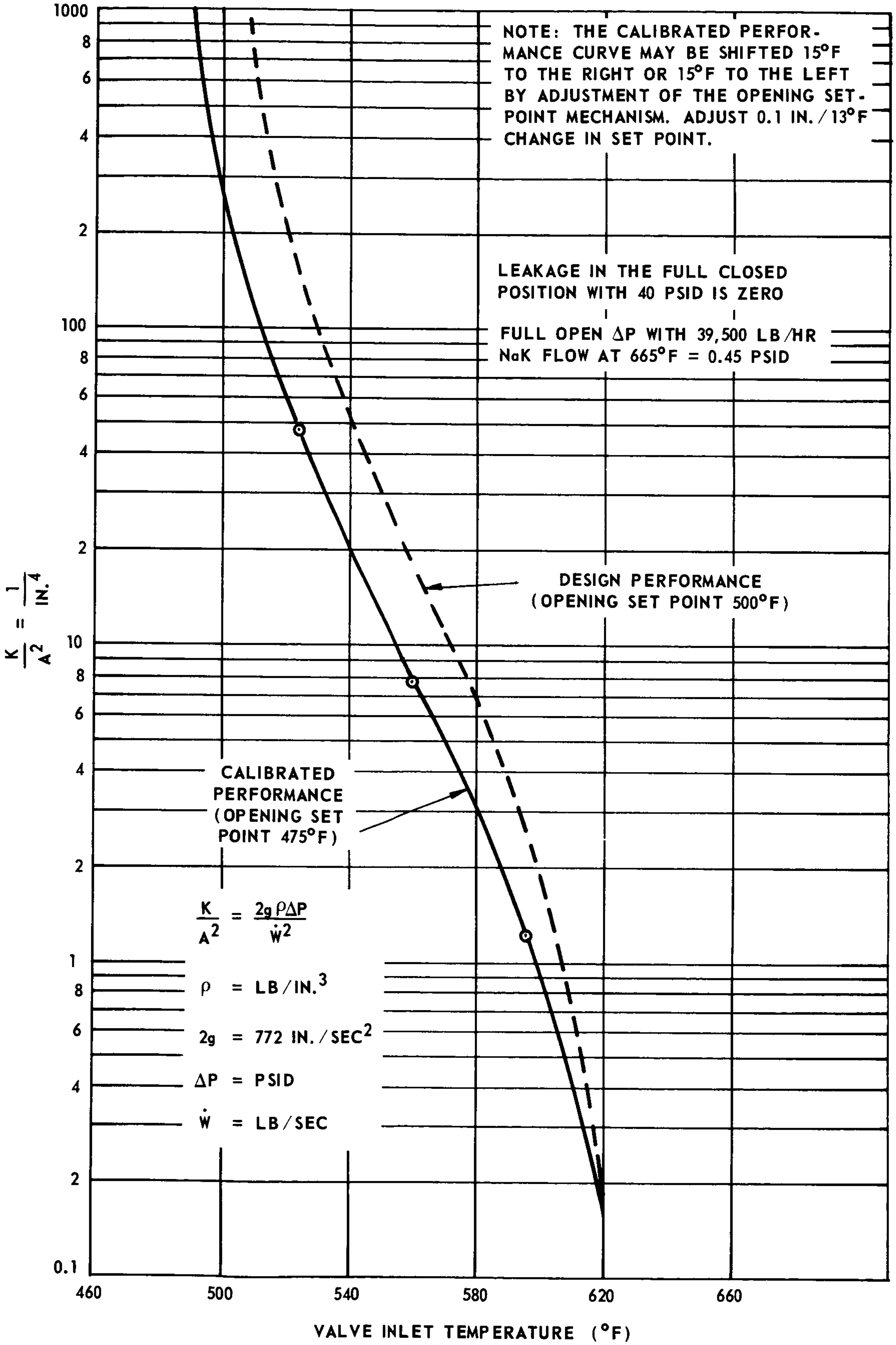
Vinson Temperature Control Valve

Figure II-23



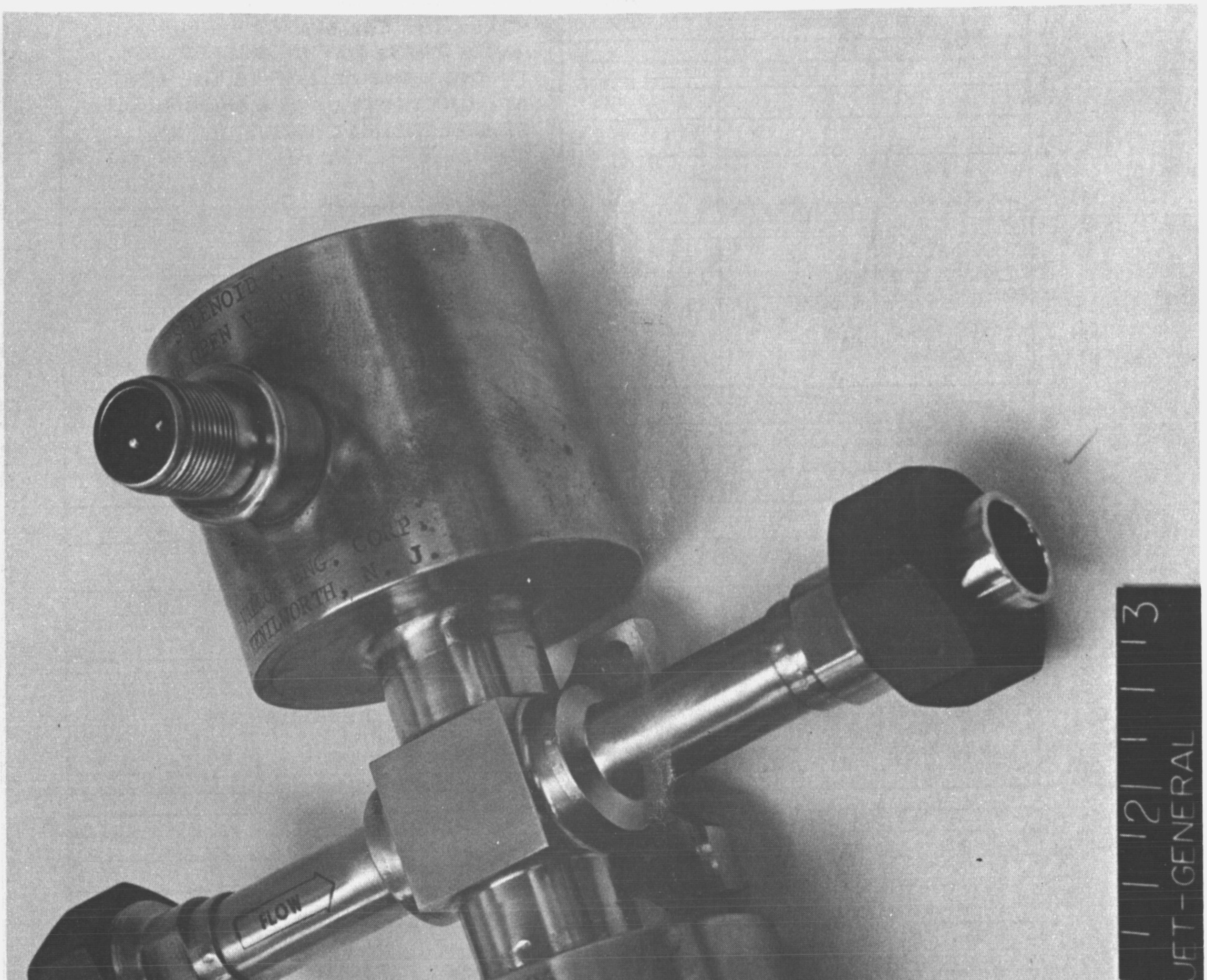
Total Performance with Vinson TCV (S/N 100G)

Figure II-24



Total Performance with Vinson TCV (S/N 101G)

Figure II-25

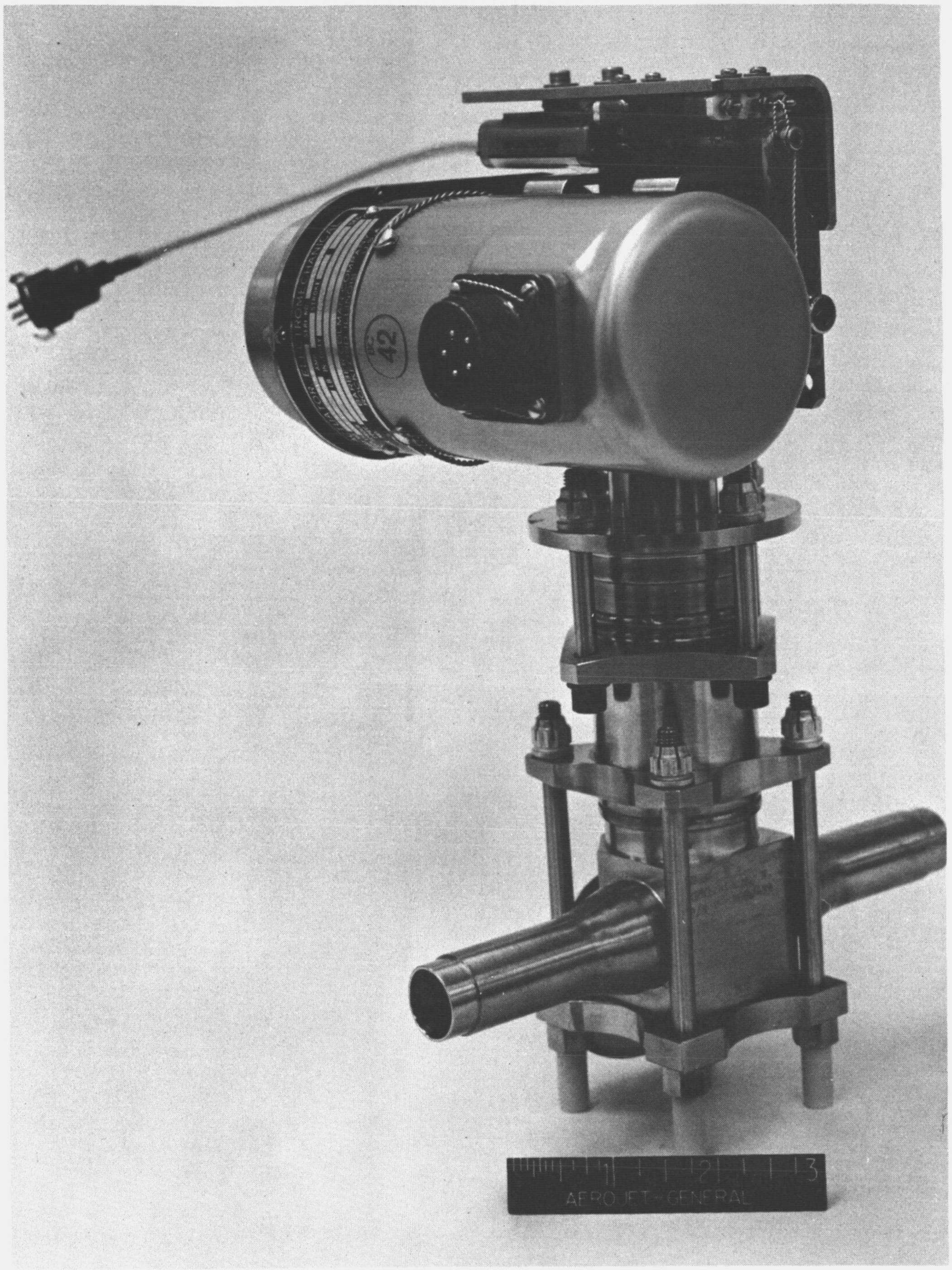


SNAP-8 Double Solenoid Latch Valve

466-419

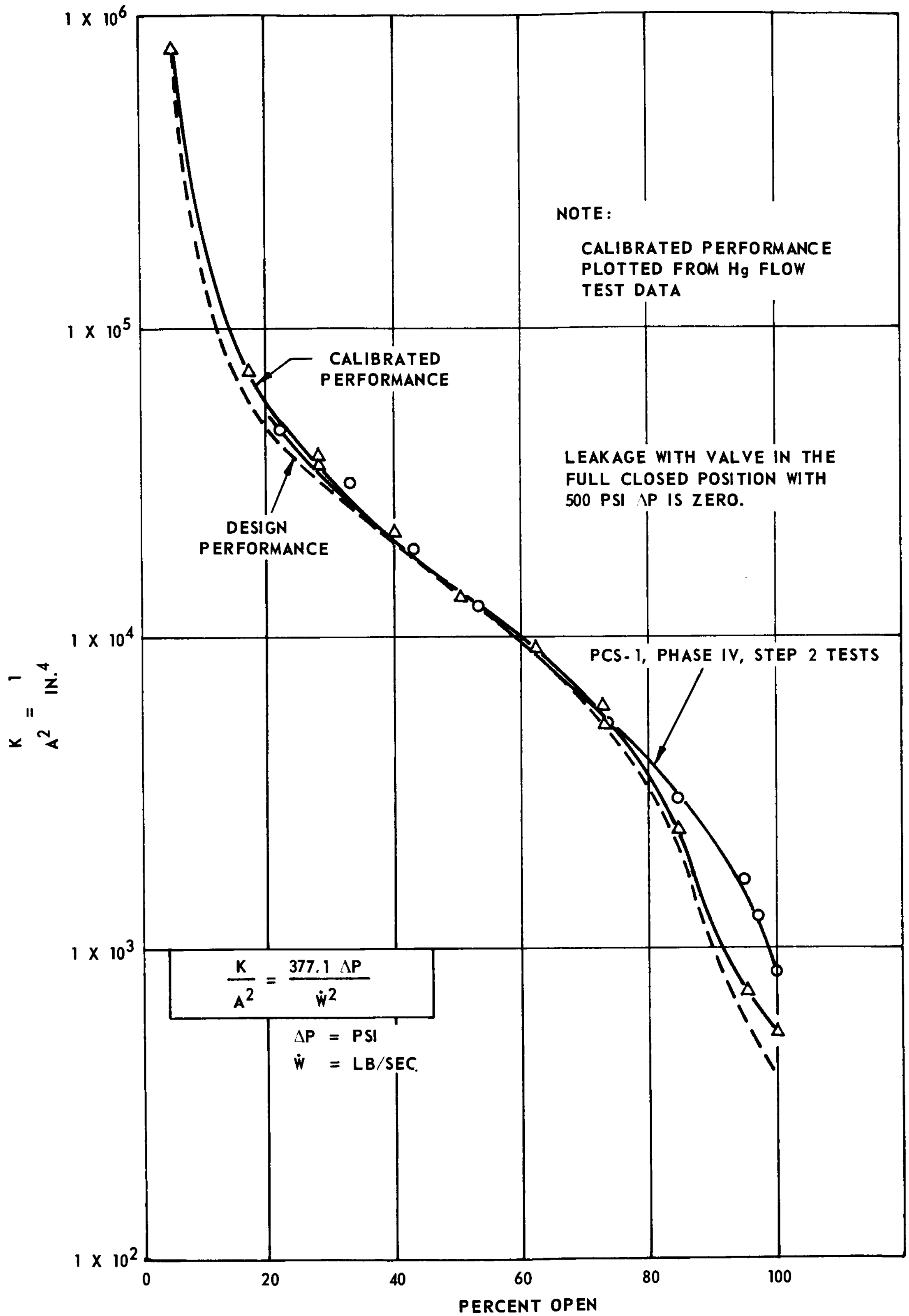
Figure II-26

1066-586



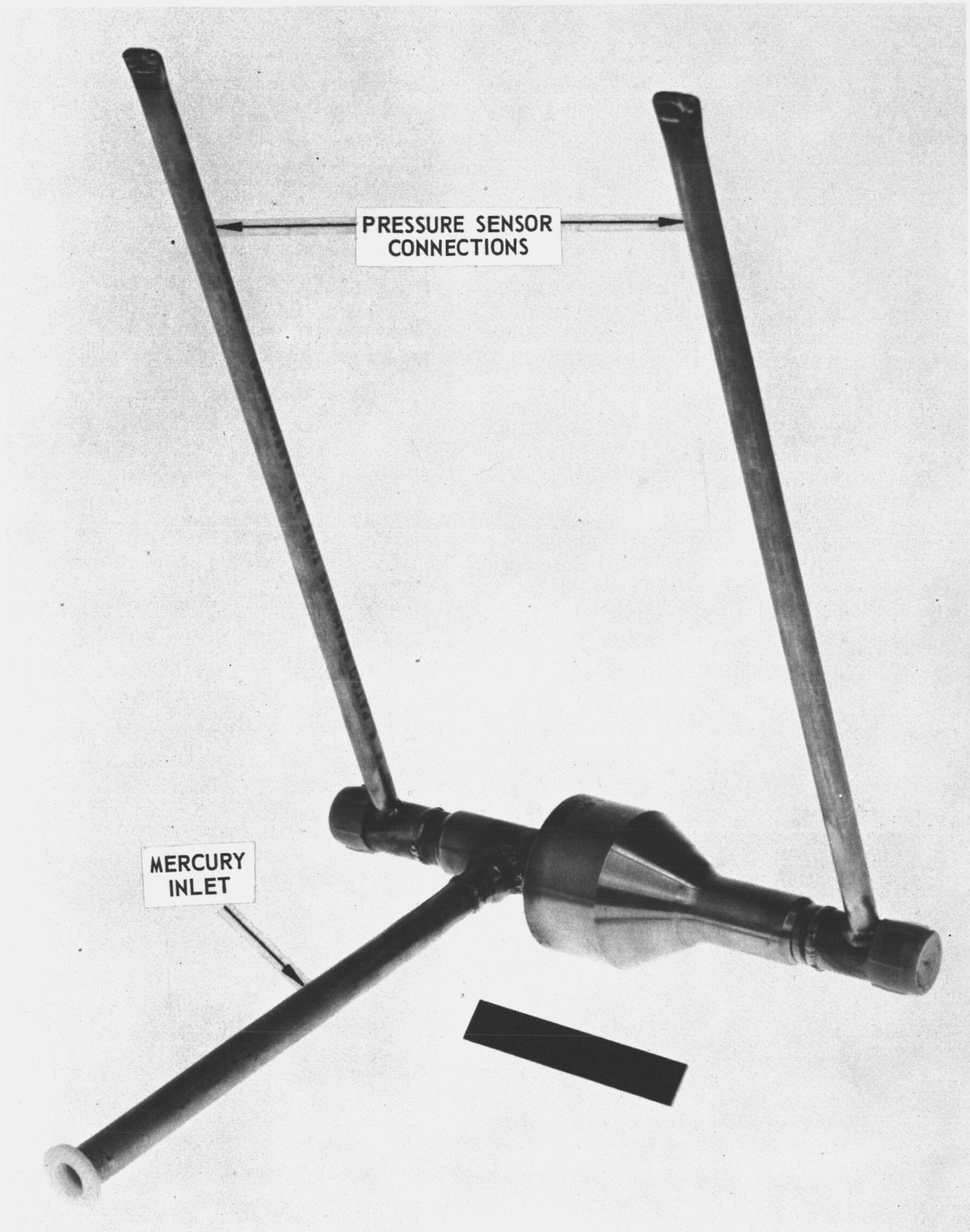
SNAP-8 Mercury Flow Control Valve

Figure II-27



Flow Characteristics - SNAP-8 Mercury Flow Control Valve

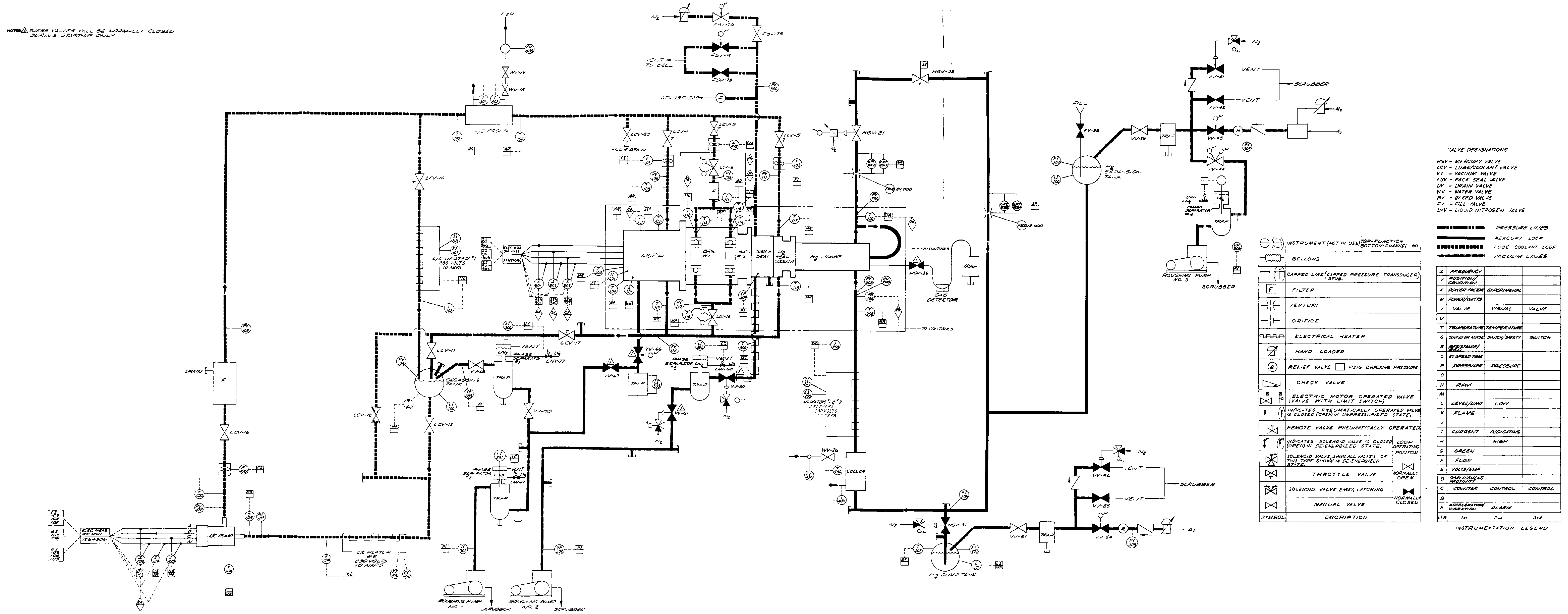
Figure II-28



Isolation Check Valve

Figure II-29

167-NF-1302



Liquid Mercury Loop 5 Configuration, Phase 1 P & I Diagram

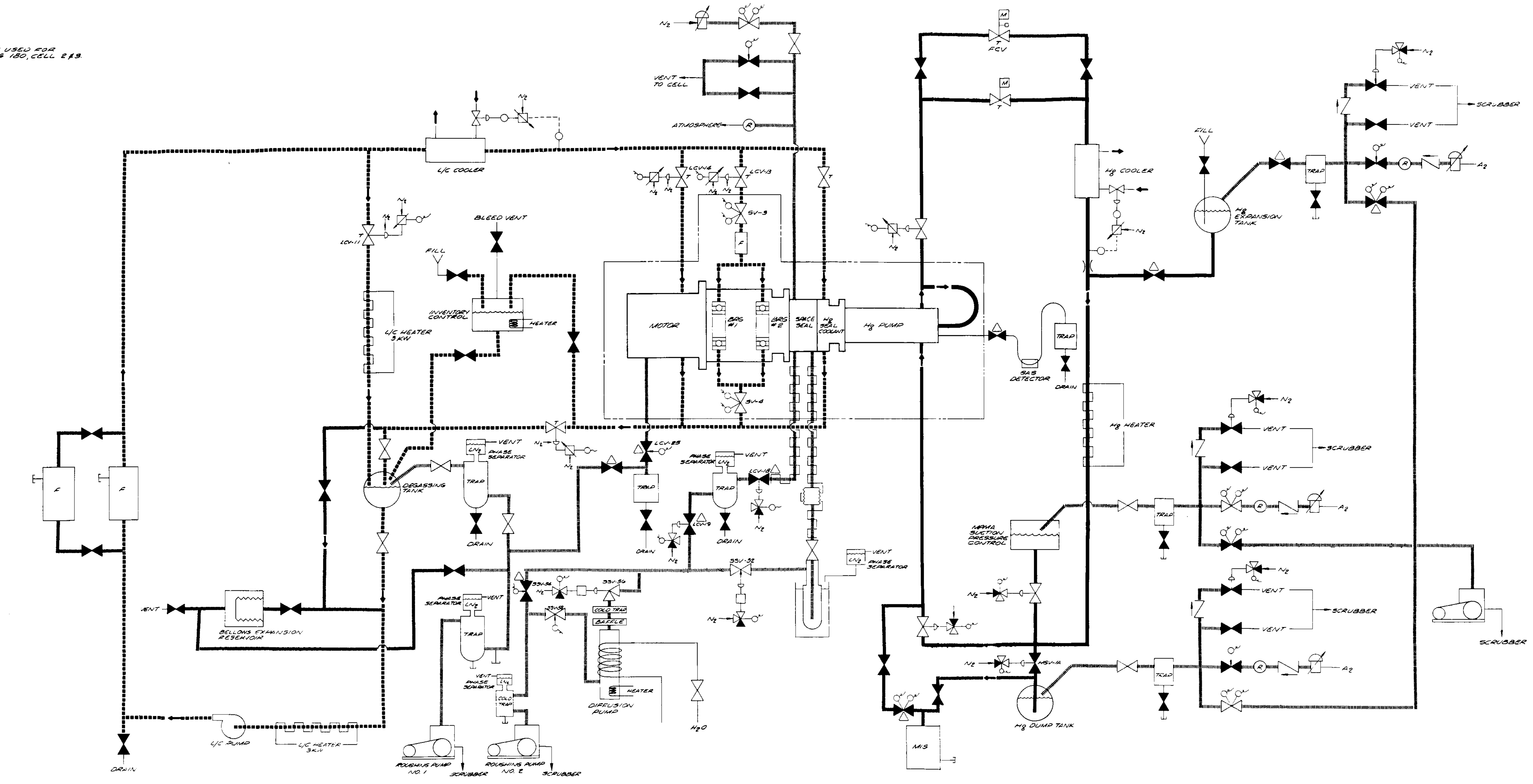
III-2-1

III-2-2

Figure III-2 - 3

267-NF-1104

NOTES: △ THIS P&I DIAGRAM TO BE USED FOR LML-5, PHASE 2 IN BLDG 180, CELL 2&3.



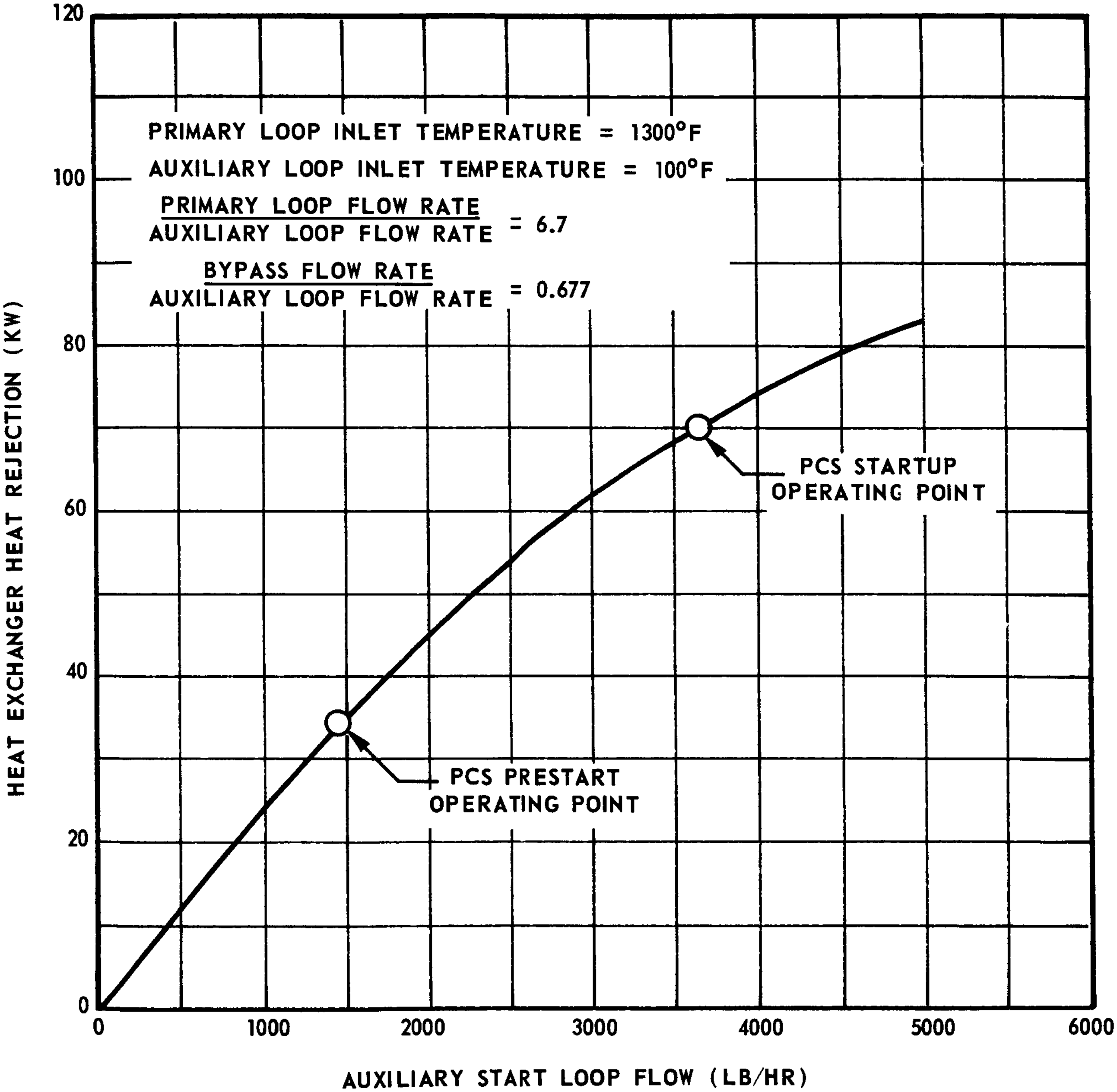
Liquid Mercury Loop 5 - Phase 2 P & I Diagram

III-1-1

III-1-2

Figure III-1-3

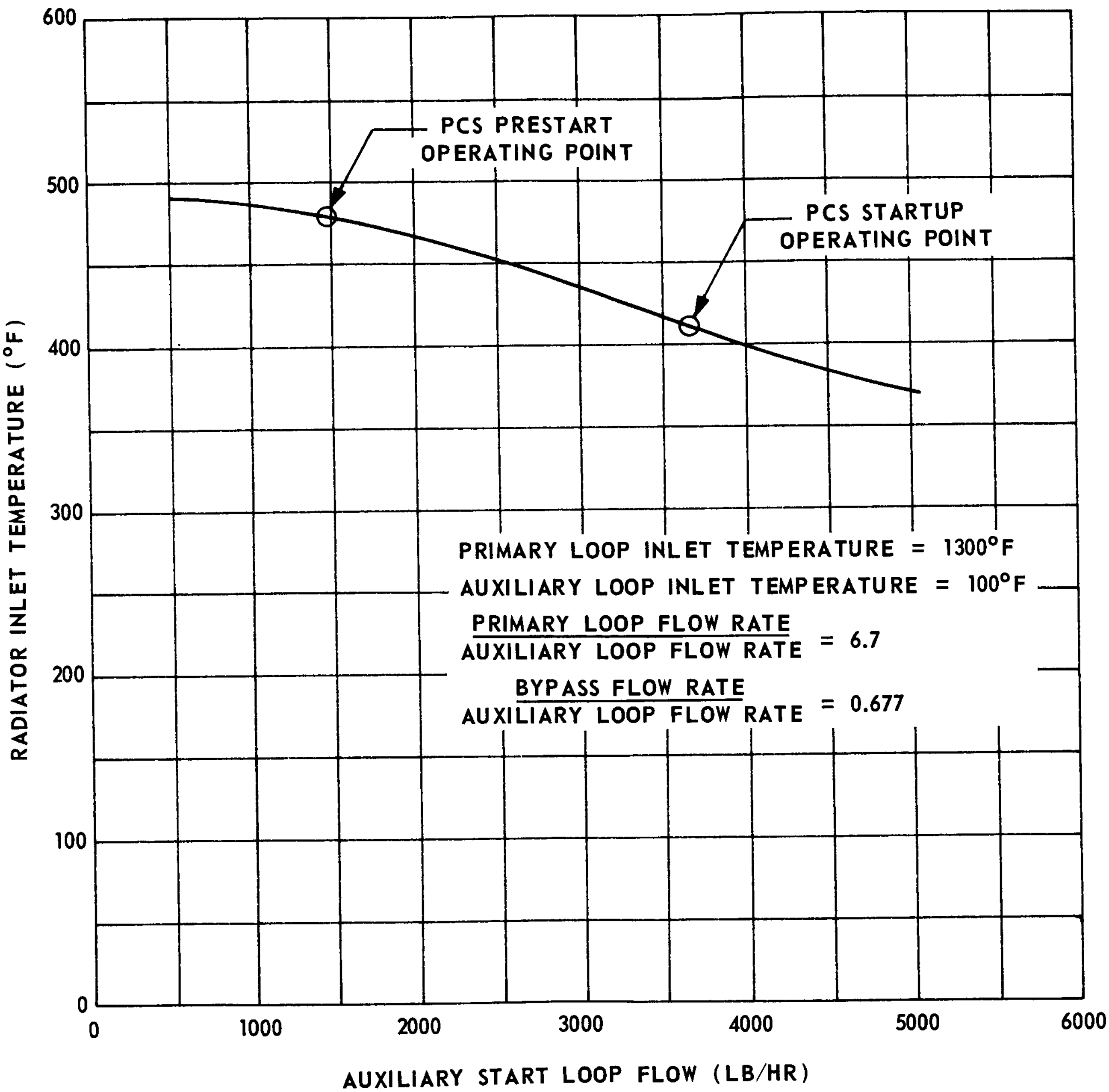
167-NF-1271



PCS Start Performance - Heat Exchanger Heat Rejection

Figure IV-1

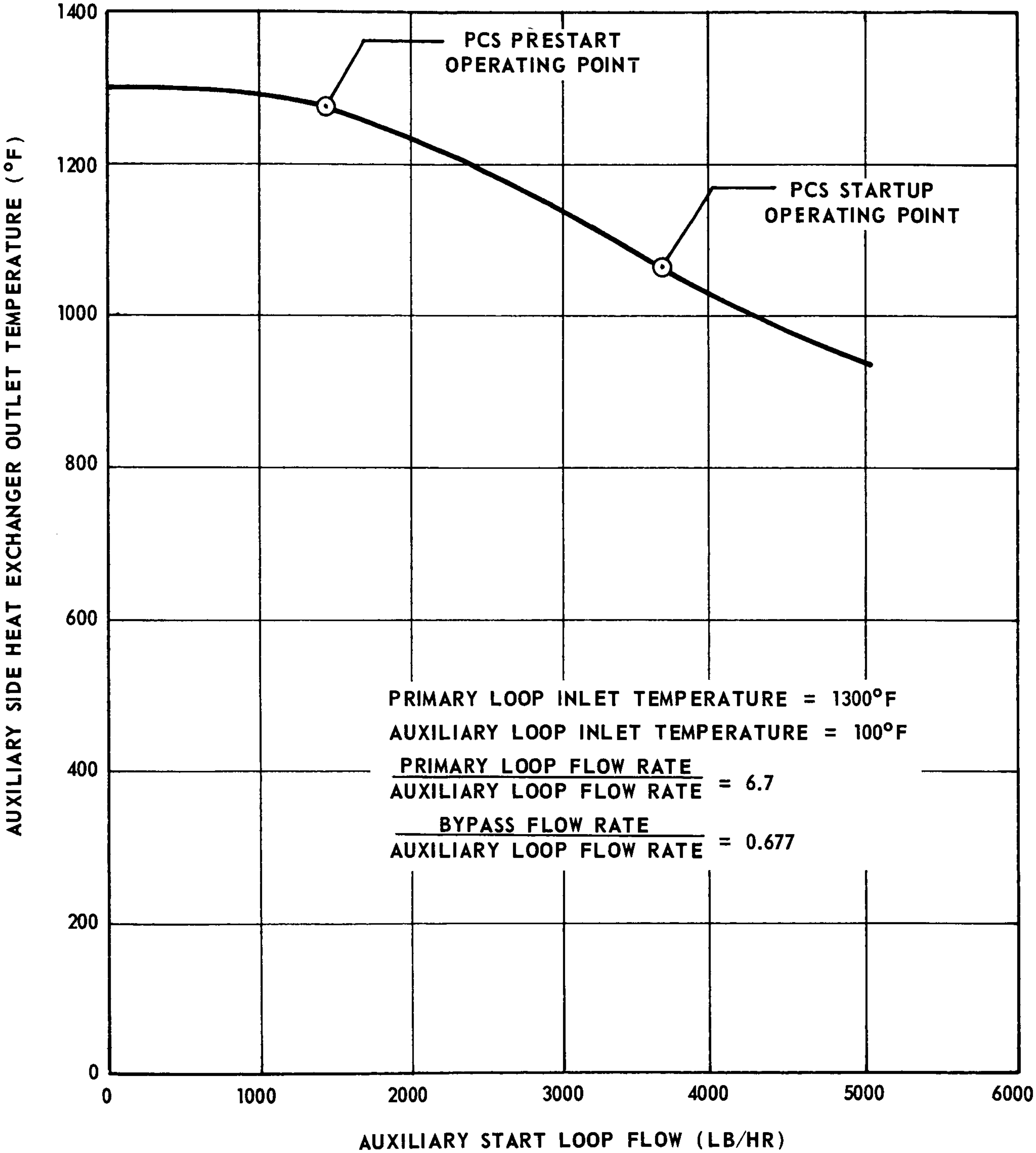
167-NF-1272



PCS Start Performance - Radiator Inlet Temperature

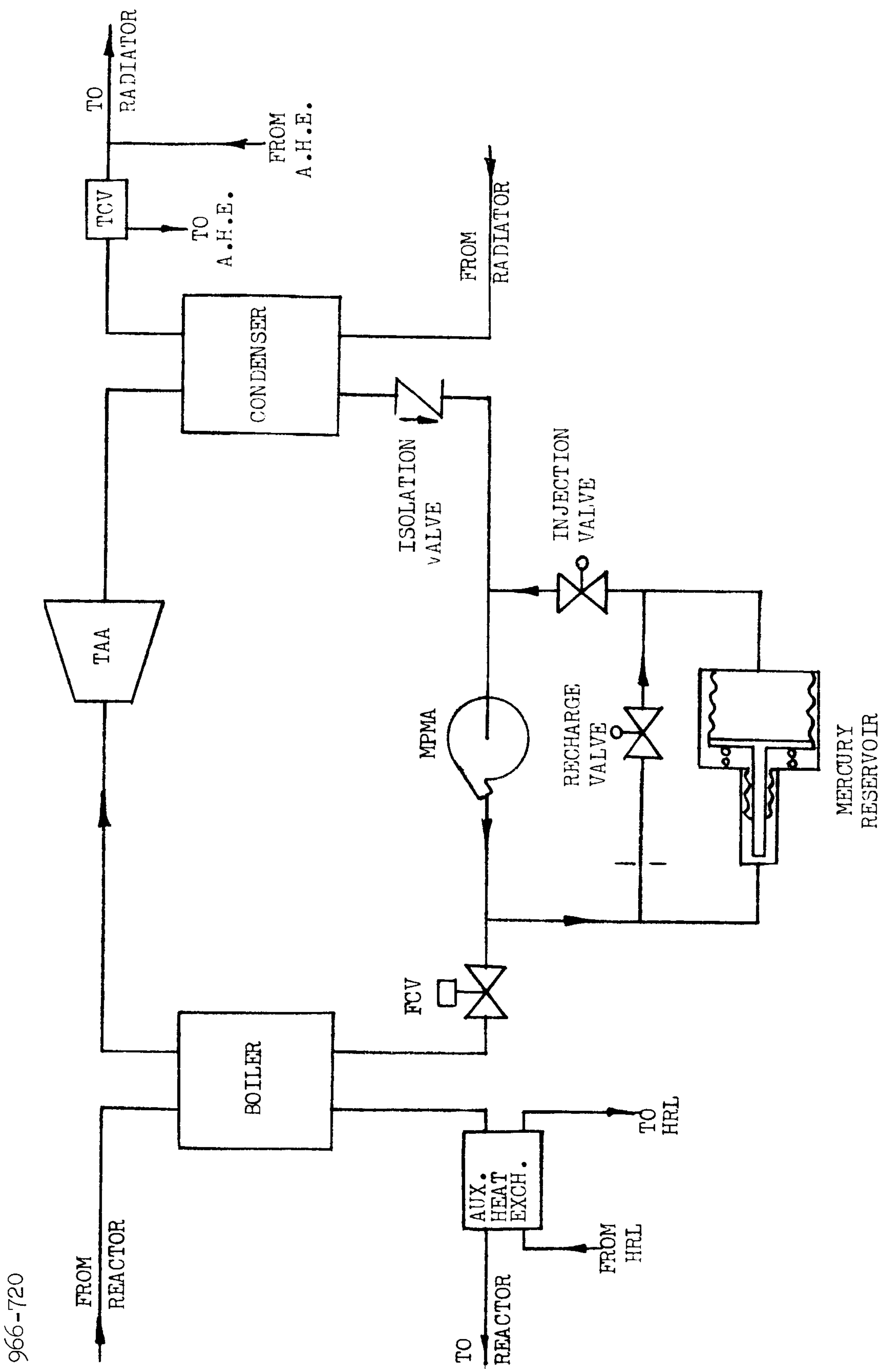
Figure IV-2

167-NF-1273



PCS Start Performance - Heat Exchanger Outlet Temperature

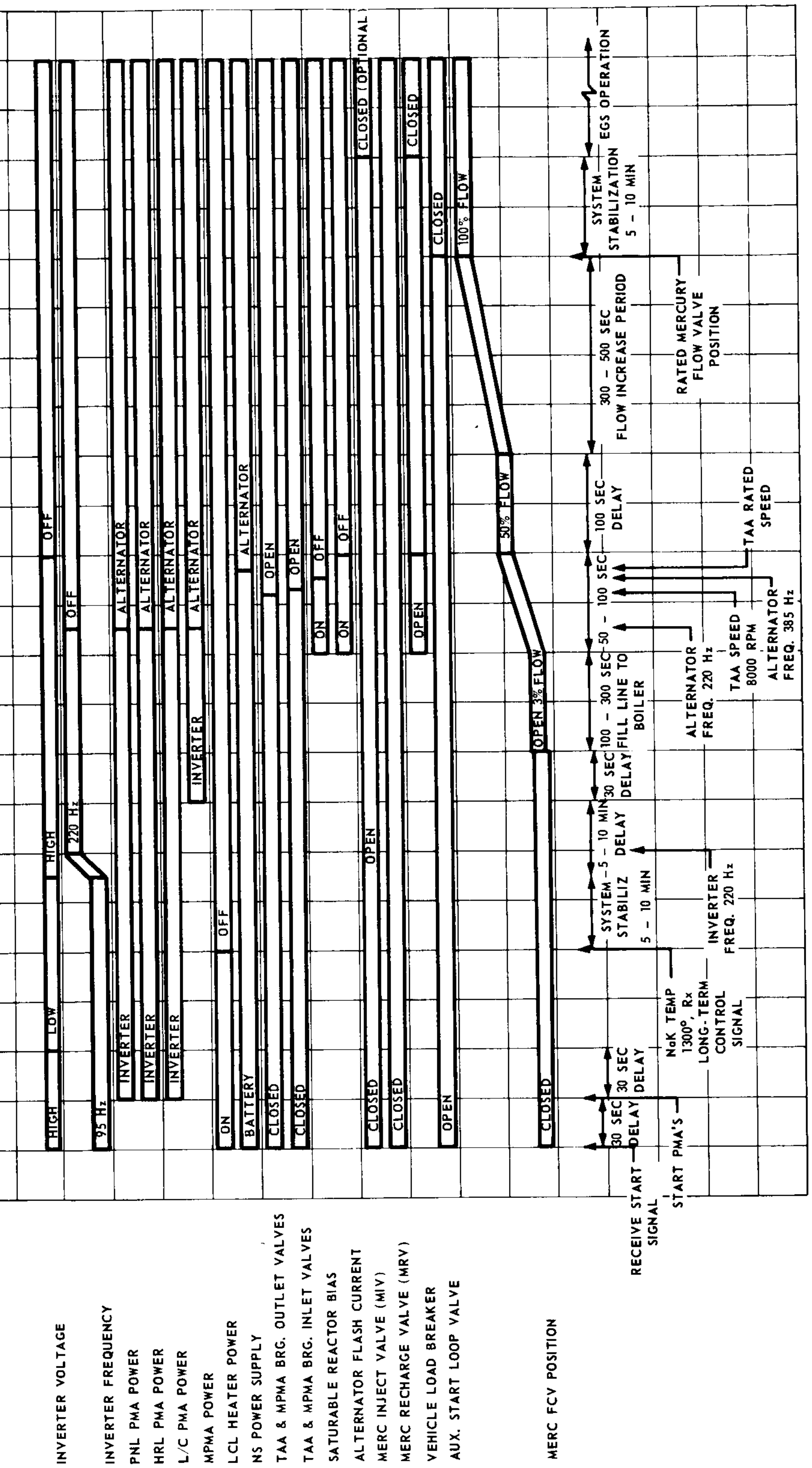
Figure IV-3



Recommended Restart Concept

Figure V-1

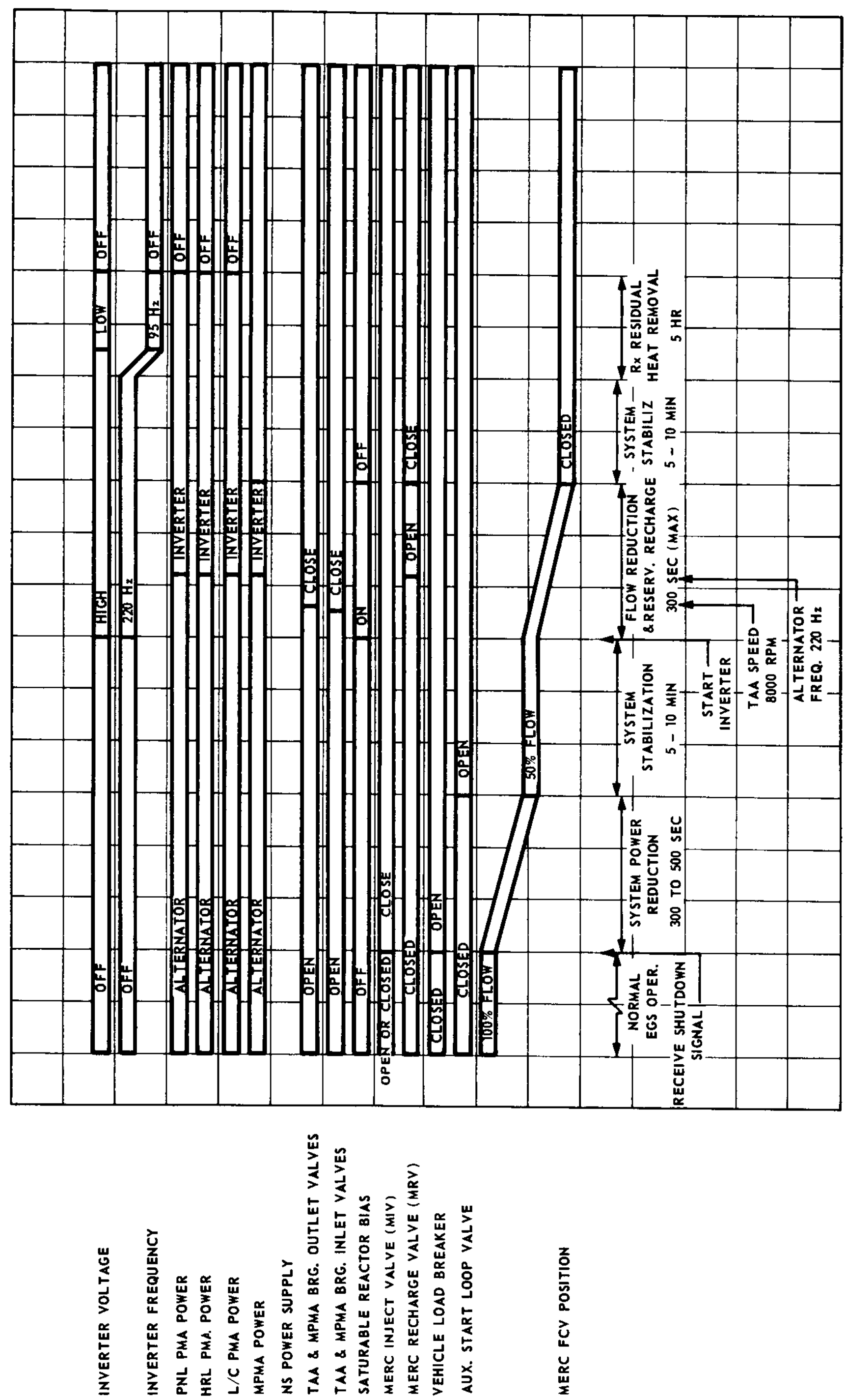
167-NF-1314



PCS Programmer Start Sequence (Preliminary)

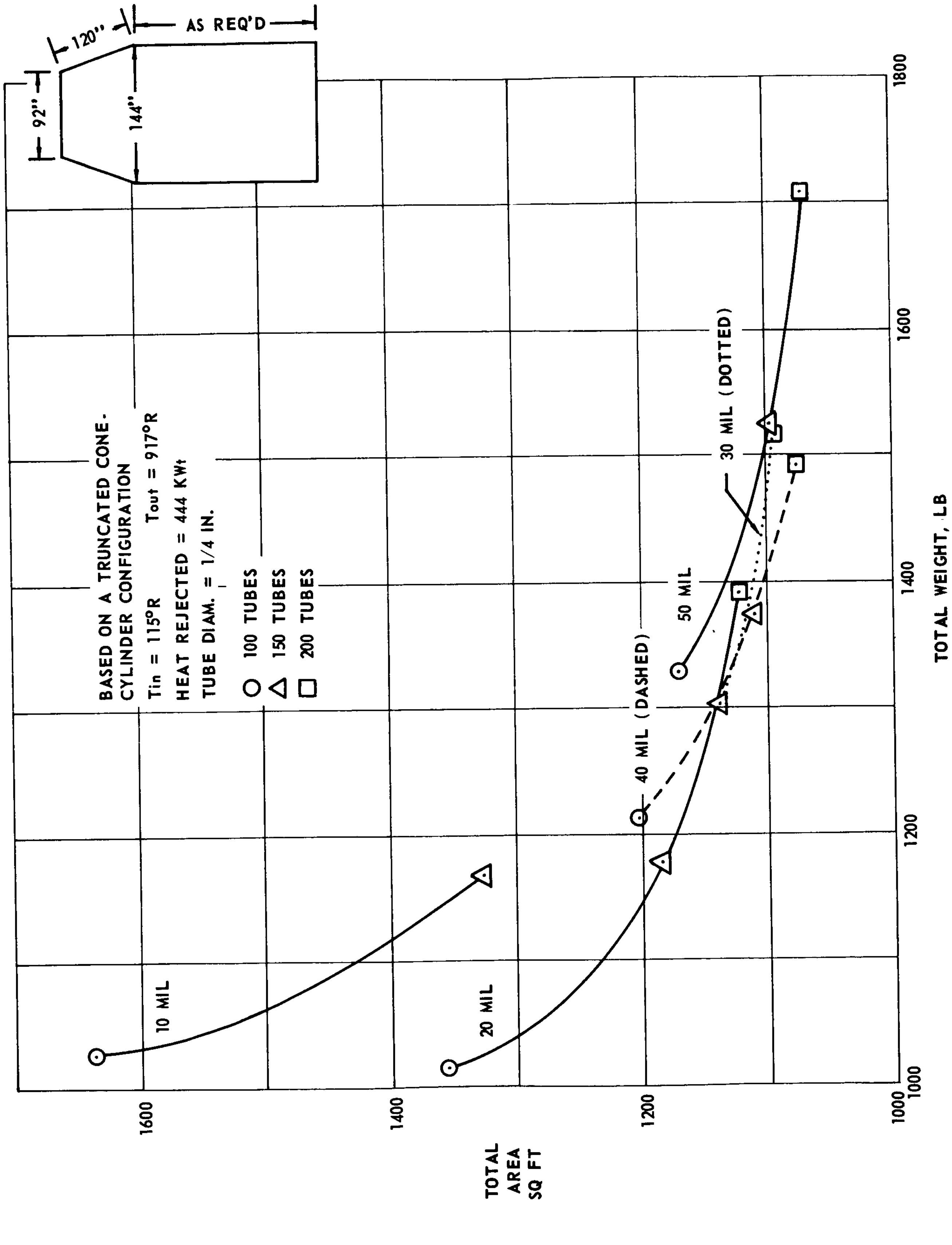
Figure V-2

167-NF-1315



PCS Programmer - Normal Shutdown Sequence (Preliminary)

Figure V-3

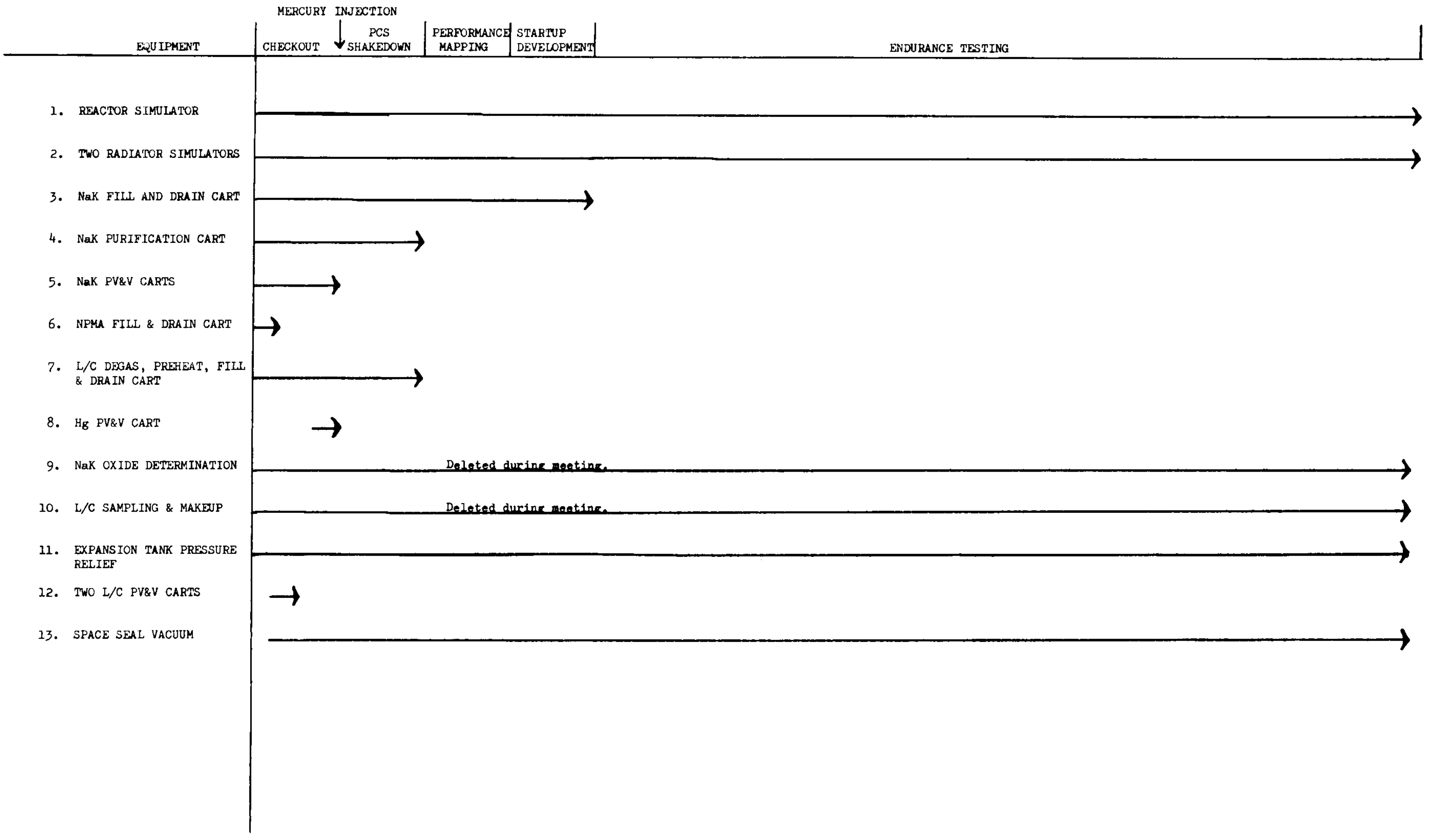


HRL Radiator Design Based on a Truncated Cone-Cylinder Configuration

167-NF-1311

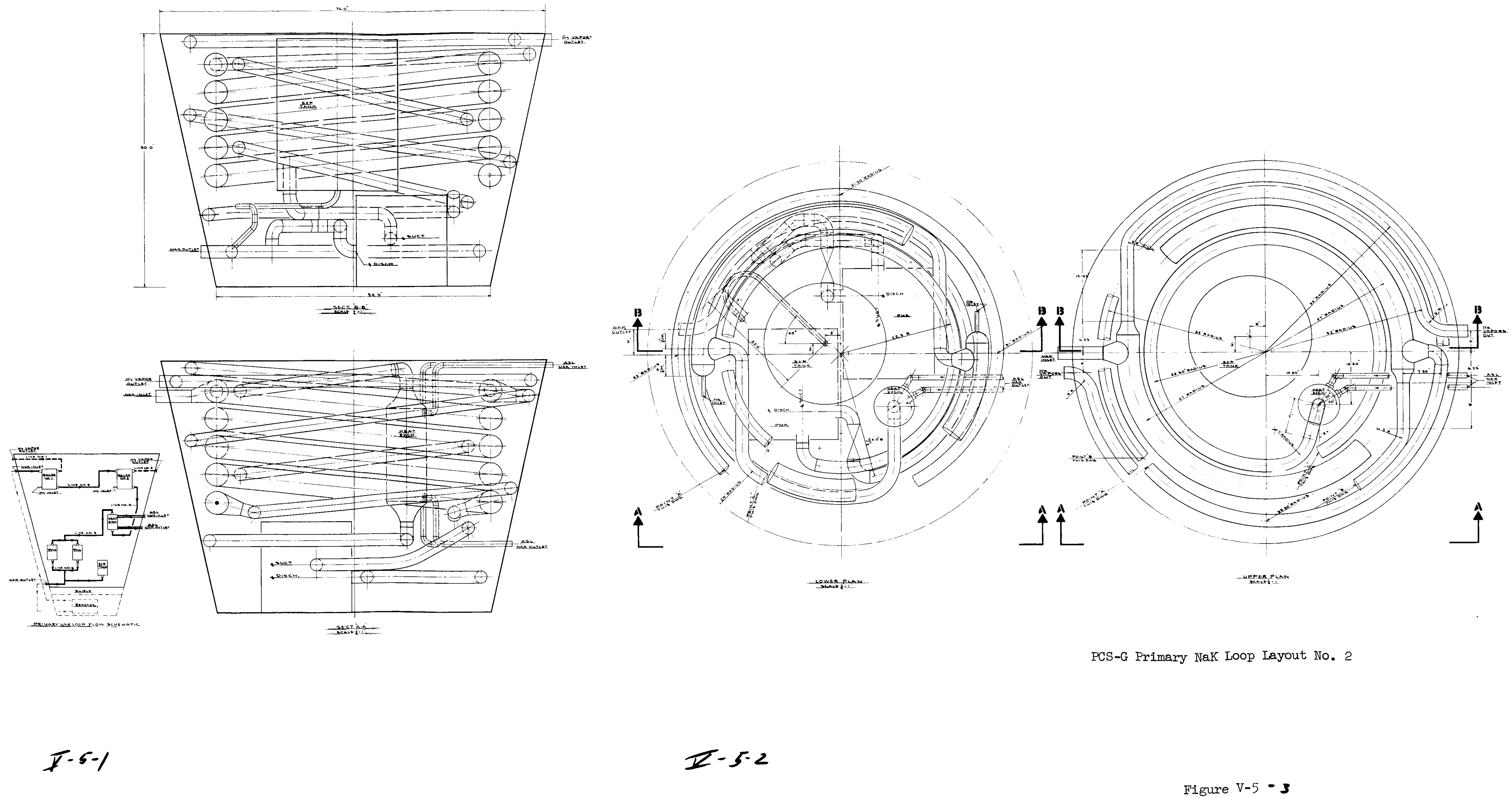
Figure V-4

167-NF-1289



Sequence of Support Equipment Connection - First PCS-G Test

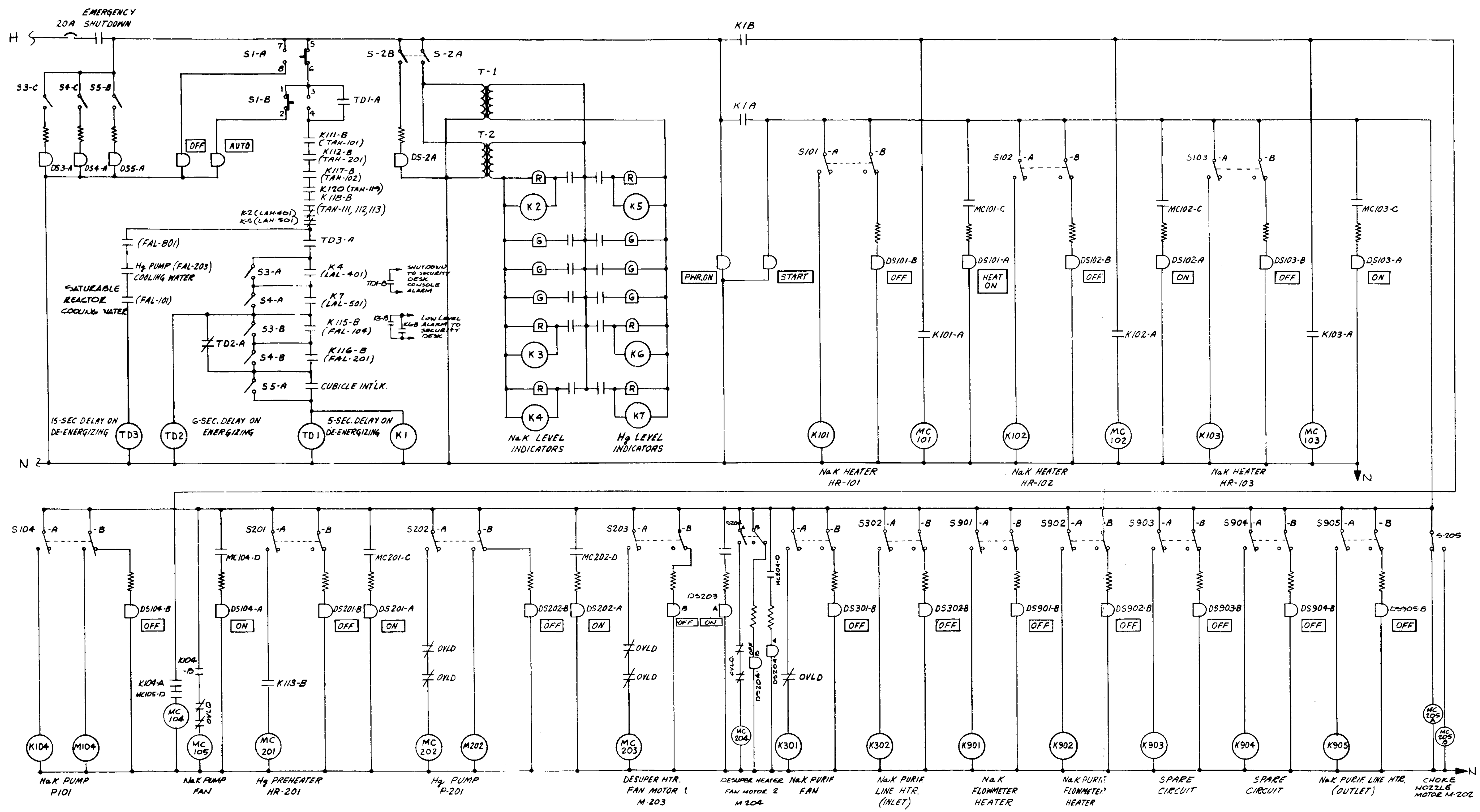
Figure V-6



PCS-G Primary NaK Loop Layout No. 2

Figure V-5 - 3

167-NF-1296



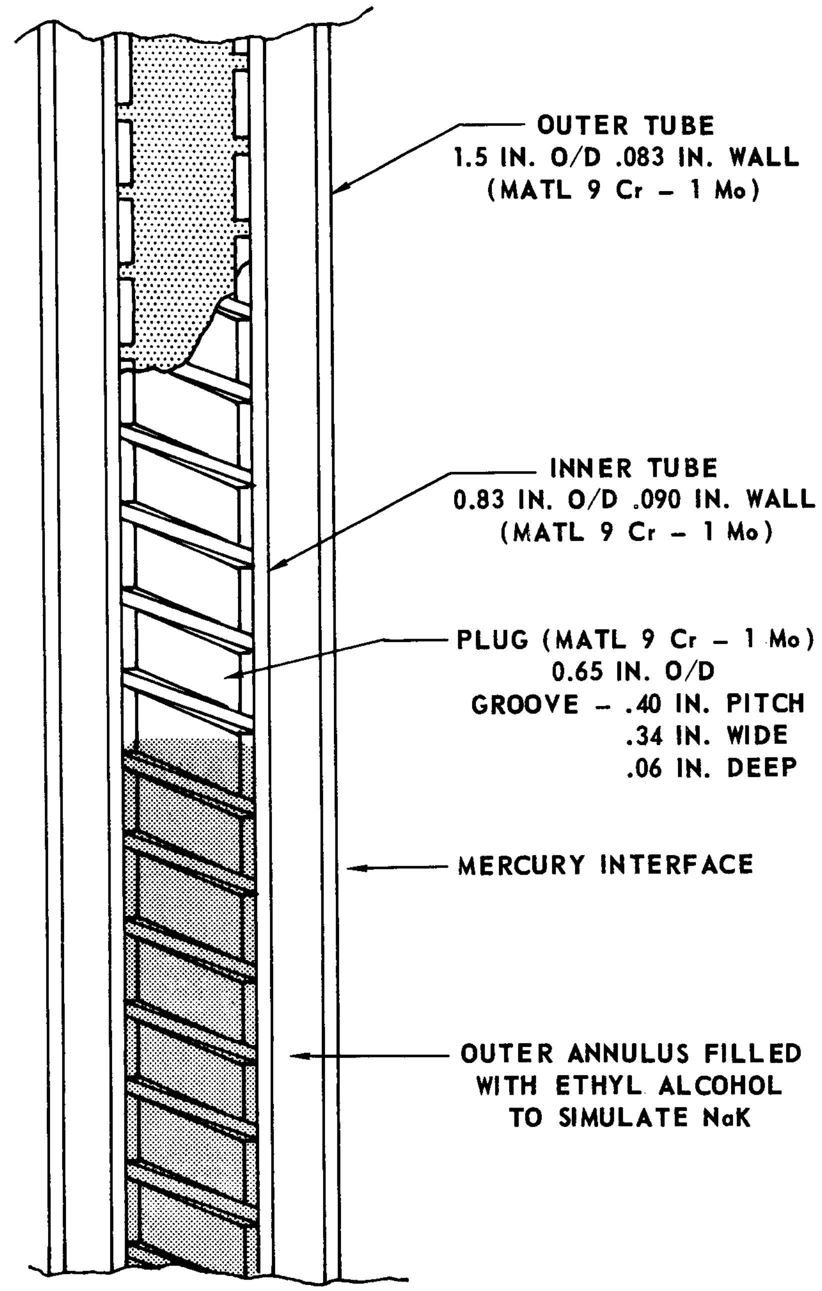
NOTE: ALL RESISTORS 1500Ω, 10W

V-13-1

Control and Power Schematic - SNAP-8 Seventh-Scale Loop (Sheet 2)

Figure V-13-2

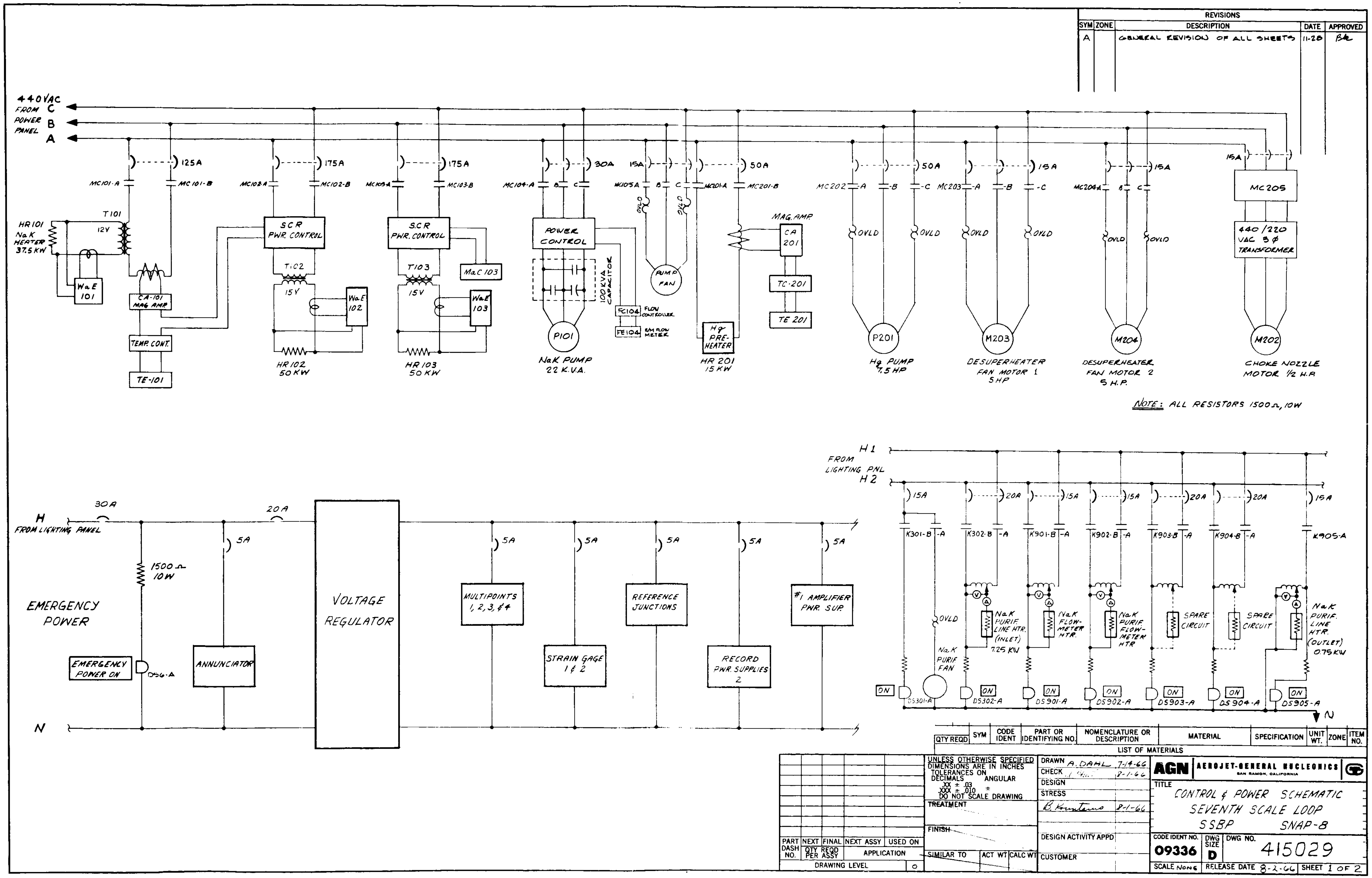
167-NF-1305



Boiler Mockup Section (Full Size)

Figure V-14

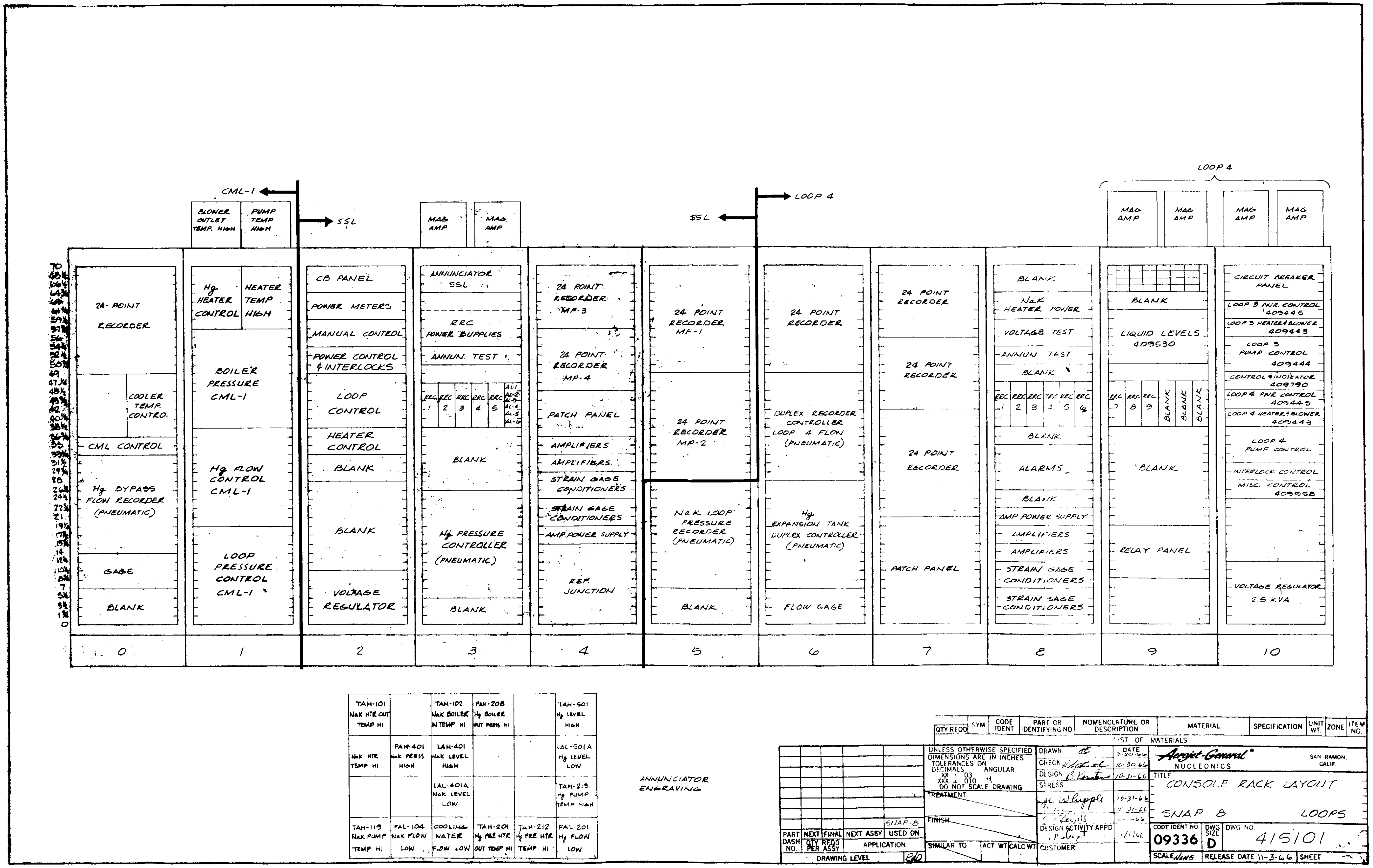
167-NF-1295



Control and Power Schematic - SNAP-8 Seventh-Scale Loop (Sheet 1)

Figure V-12-2

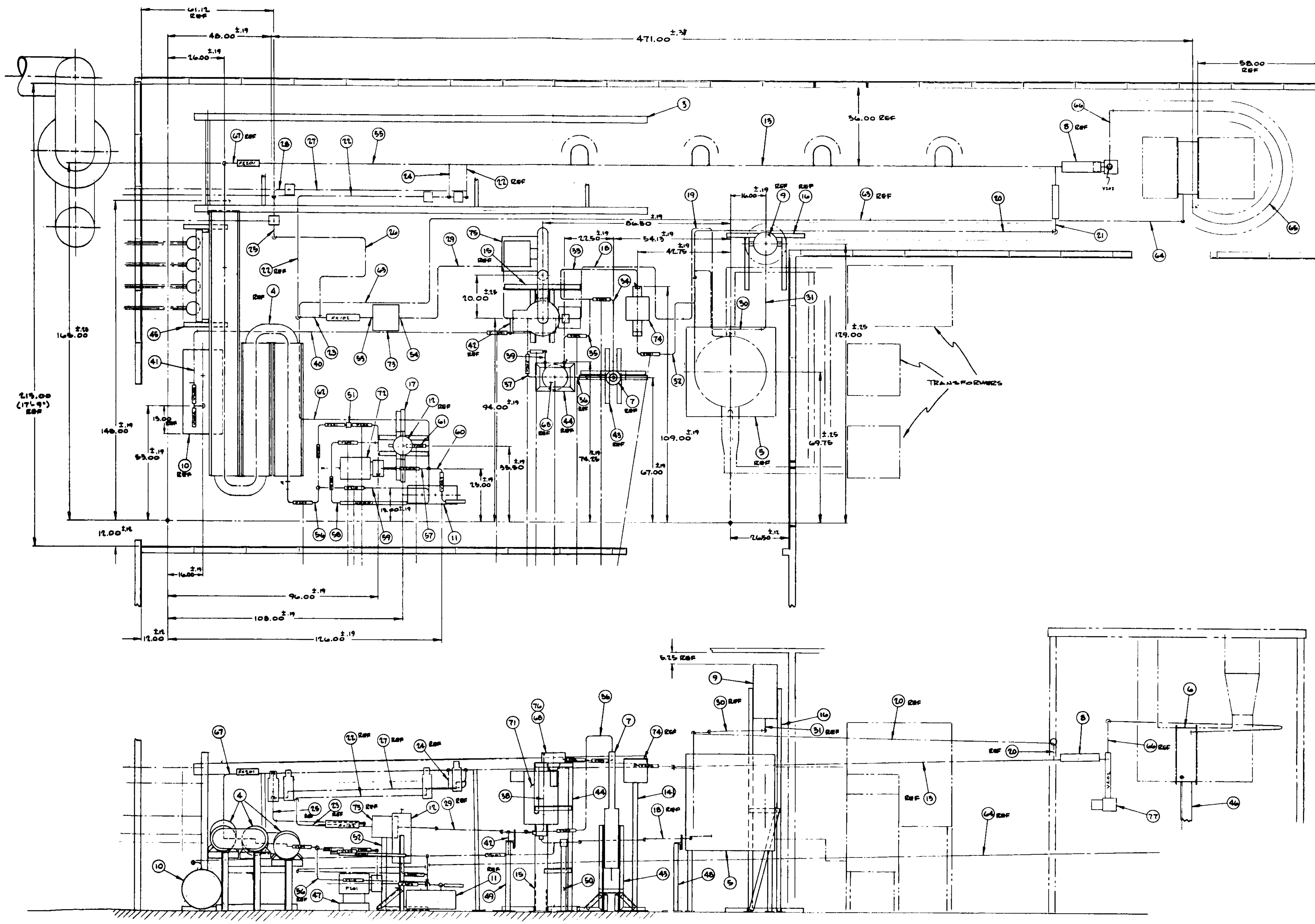
167-NF-1294



Console Layout - SNAP-8 Seventh-Scale Loops

Figure V-11-2

167-NF-1291

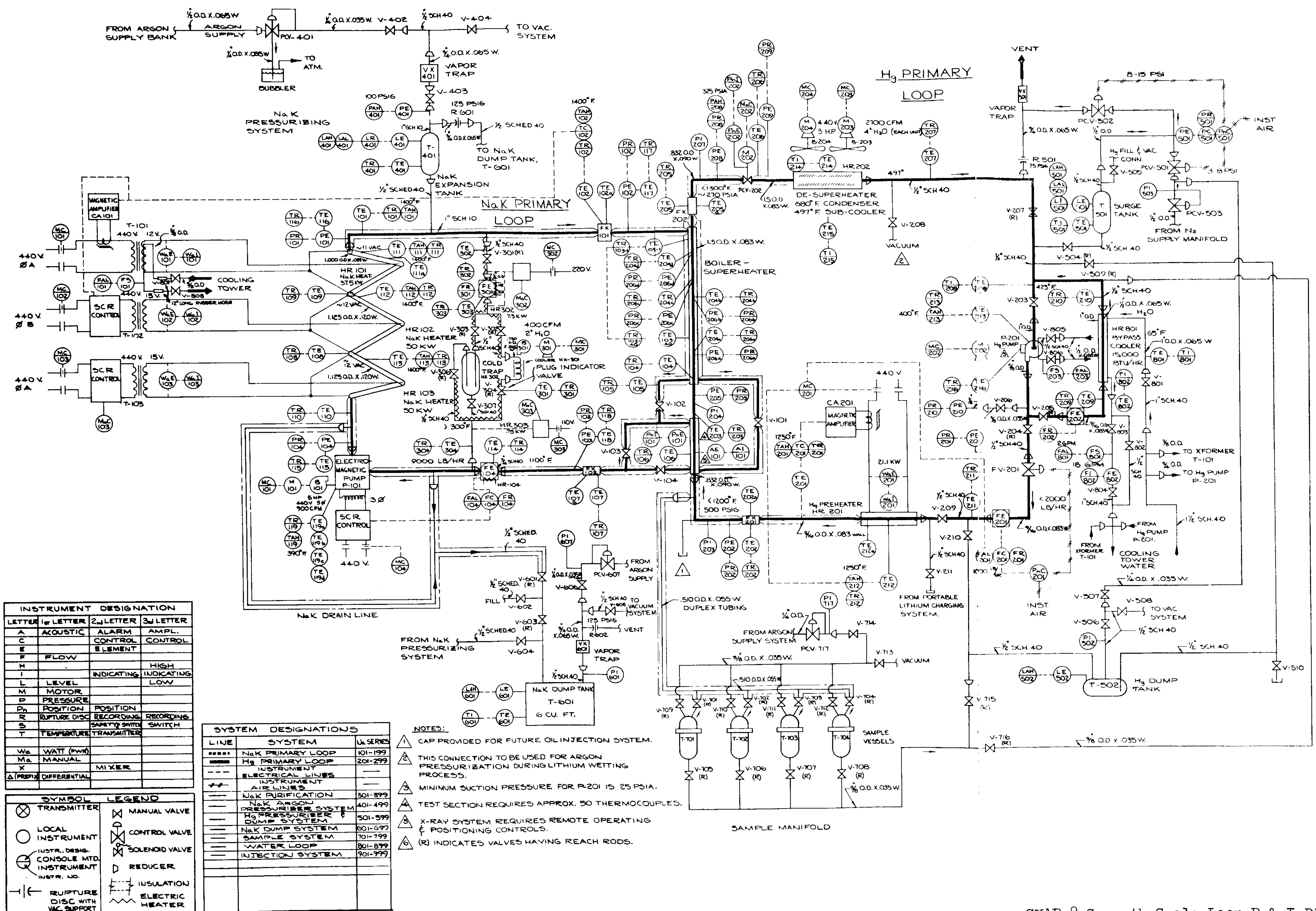


V-8-1

SNAP-8 Seventh-Scale Loop Assembly - Layout and Elevation

Figure V-8-2

167-NF-1290



LETTER	1st LETTER	2nd LETTER	3rd LETTER
A	ACOUSTIC	ALARM	AMPL.
C		CONTROL	CONTROL
E		ELEMENT	
F	FLOW		
H			HIGH
I		INDICATING	INDICATING
L	LEVEL		LOW
M	MOTOR		
P	PRESSURE		
Po	POSITION	POSITION	
R	RUPTURE DISC	RECORDING	RECORDING
S		SAFETY SWITCH	SWITCH
T	TEMPERATURE	TRANSMITTER	
Wa	WATT (PWR)		
Ma	MANUAL		
X		MIXER	
Δ (PREFIX)	DIFFERENTIAL		

SYMBOL LEGEND

- TRANSMITTER
- LOCAL INSTRUMENT
- CONSOLE MTD. INSTRUMENT (INSTR. DESIG., INSTR. NO.)
- RUPTURE DISC WITH VAC. SUPPORT
- MANUAL VALVE
- CONTROL VALVE
- SOLENOID VALVE
- REDUCER
- INSULATION
- ELECTRIC HEATER

SYSTEM DESIGNATIONS

LINE	SYSTEM	Ua SERIES
	NaK PRIMARY LOOP	101-199
	Hg PRIMARY LOOP	201-299
	INSTRUMENT ELECTRICAL LINES	—
	INSTRUMENT AIR LINES	—
	NaK PURIFICATION	301-399
	NaK ARGON PRESSURIZER SYSTEM	401-499
	Hg PRESSURIZER & DUMP SYSTEM	501-599
	NaK DUMP SYSTEM	601-699
	SAMPLE SYSTEM	701-799
	WATER LOOP	801-899
	INJECTION SYSTEM	901-999

NOTES:

1. CAP PROVIDED FOR FUTURE OIL INJECTION SYSTEM.
2. THIS CONNECTION TO BE USED FOR ARGON PRESSURIZATION DURING LITHIUM WETTING PROCESS.
3. MINIMUM SUCTION PRESSURE FOR P-201 IS 25 PSIA.
4. TEST SECTION REQUIRES APPROX. 50 THERMOCOUPLES.
5. X-RAY SYSTEM REQUIRES REMOTE OPERATING & POSITIONING CONTROLS.
6. (R) INDICATES VALVES HAVING REACH RODS.

SNAP-8 Seventh-Scale Loop P & I Diagram

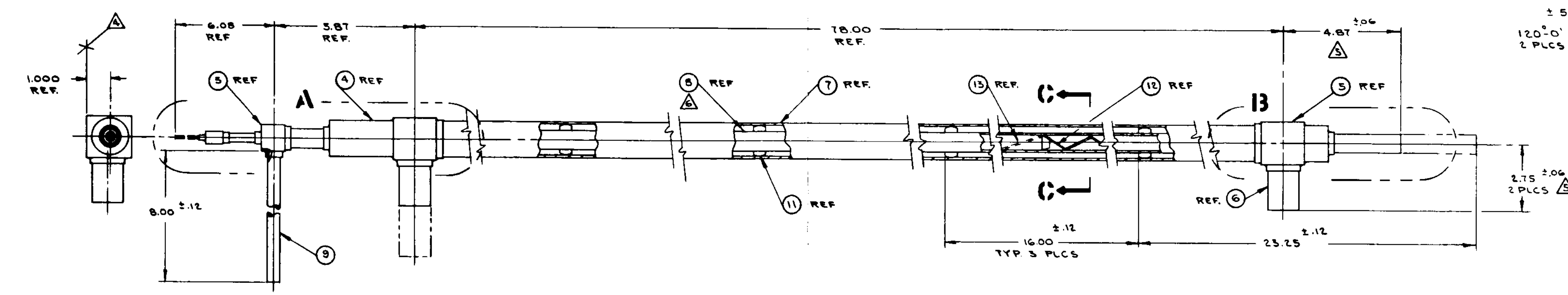
Figure V-7-2

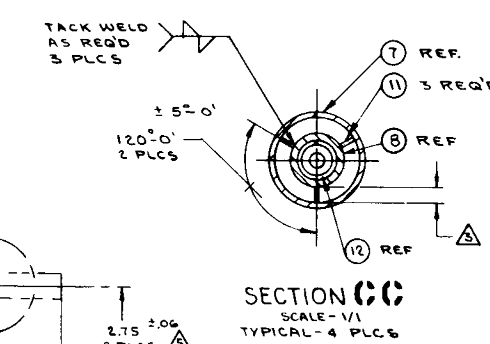
167-NF-1293

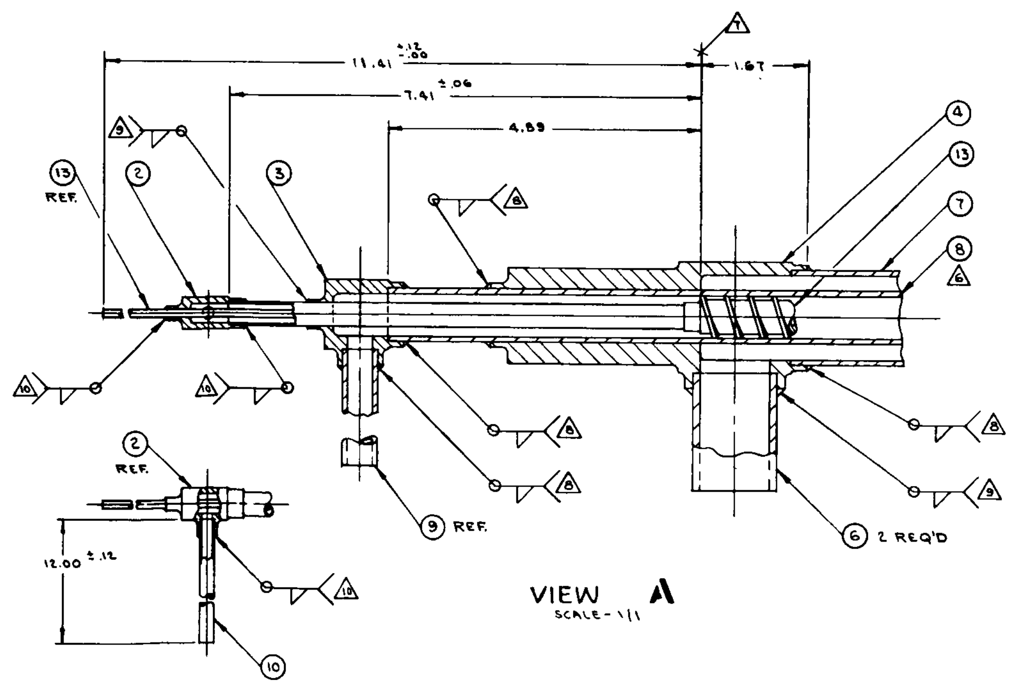
NOTES

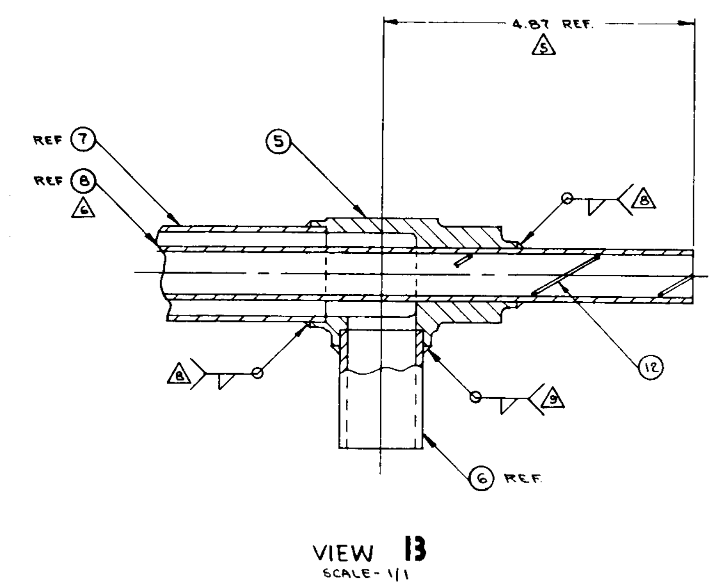
1. REMOVE ALL BURRS AND SHARP EDGES.
2. 64 ALL MACHINED SURFACES UNLESS OTHERWISE SPECIFIED.
3. THESE DIMENSIONS TO BE DETERMINED AFTER SWAGING OF ITEM 8 TO ITEM 13.
4. THESE SURFACES ON ITEM 4 & 5 TO BE IN THE SAME PLANE WITHIN .09 AFTER WELDING.
5. CUT TO DIMENSIONS SHOWN AT FINAL ASS'Y (415291-1).
6. SWAGE ITEM 8 OVER ITEM 13 TO OBTAIN AN INTERFERENCE FIT BETWEEN THE INSIDE DIAMETER OF ITEM 8 AND THE O. D. OF ITEM 13 WITH A MINIMUM DEFORMATION OF ITEM 8 AS SPECIFIED BY THE COGNIZANT ENGINEER. SWAGE ENTIRE LENGTH OF ITEM 8 HOLDING THE SAME O. D. AS DETERMINED BY SWAGING OVER PLUG LENGTH.
7. START OF HELIX ON ITEM 13 TO BE IN LINE WITH ITEM 6 INSIDE DIAMETER, WITHIN .06, AS SHOWN.
8. USE 9Cr-1Mo FILLER ROD FOR ALL 9Cr-1Mo TO 9Cr-1Mo JOINTS.
9. USE CRES 310 FILLER ROD 9Cr-1Mo TO CRES JOINTS.
10. USE 316L FILLER ROD FOR CRES TO CRES JOINTS.
11. CLEAN ALL 9Cr-1Mo PARTS PER AGC 60248 PRIOR TO WELDING.
12. CLEAN ALL 316 PARTS PER AGC 10319/3 METHOD II, PART (b) STEPS 1 THROUGH 9. DEGREASE PARTS BEFORE PICKLING.
13. FABRICATION SHALL BE IN ACCORDANCE WITH APPLICABLE SECTIONS OF THE ASME CODE FOR PRESSURE PIPING
    a) T. I. G. WELD PER AGC-STD-1194 FOR ALL WELDED JOINTS.
    b) ALL 9Cr-1Mo WELD JOINTS MUST BE PRE-HEATED 400°F, BEFORE WELDING.
    c) ALL 9Cr-1Mo WELD SHALL BE HEAT TREATED TO 1350°F ± 25°F FOR 30 MINUTES, THEN COOLED IN A STILL INERT ATMOSPHERE. HEAT TREATMENT TO START AFTER WELD COOLS TO 300°F POST HEAT TREATMENT SHALL BE IN A SUITABLE ATMOSPHERE TO GIVE A BRIGHT METALLIC FINISH.
14. ALL WELDS SHALL BE INSPECTED AFTER EACH ROOT PASS BY DYE PENETRANT METHOD PER MIL-STD-271, SECTION 5, GROUP I OR II. ANY FLAWS AFFECTING THE STRUCTURAL PROPERTIES OF THE ASS'Y SHALL BE REPAIRED TO THE BUYER'S SATISFACTION.
15. X-RAY INSPECT ALL WELDS PER MIL-STD-45%. ACCEPTANCE STANDARD PER MIL-R-11468 TABLE I, STD. I.
16. HELIUM LEAK CHECK USING A HELIUM MASS SPECTROMETER LEAK DETECTOR WITH A SENSITIVITY OF 10^{-9} STANDARD cc/sec/div. FOR 5 MINUTES, NO LEAKAGE ALLOWED. HELIUM LEAK CHECK INNER TUBE ASS'Y AND OUTER TUBE ASS'Y SEPARATELY.
17. PRESSURE TEST INNER TUBE TO 600.0 PSIG AND OUTER TUBE TO 75.0 PSIG FOR 15 MINUTES USING ARGON GAS. NO LEAKAGE ALLOWED.
18. CLEAN FINAL ASS'Y IN ACCORDANCE WITH AGC 10319/6, METHOD 2. DO NOT COAT WITH PROTECTIVE OIL.
19. TAG WITH PART NO. 415316-1.
20. NOMINAL SERVICE CONDITIONS:

	INNER TUBE	OUTER TUBE
PRESSURE	350 PSIA	45 PSIA
TEMPERATURE	1100°F	1250°F









QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
A/R			——	WELD ROD	CRES 316 PER MIL-R 5031 CLASS 17				
A/R			——	WELD ROD	CRES 310 PER MIL-R-5031 CLASS 3				
A/R			——	WELD ROD	9CR-1MO PER ASTM-A-182				
1			415370-1	PLUG INSERT					13
1			-12	WIRE - .062 DIA.	9 CR-1MO PER ASTM-A-182				12
12			-11	SHEET - 1/16 THK.	CRES 316 PER MIL-S-5059				11
1			-10	TUBE - 1/4 O.D. x .035 WALL	CRES 316 PER ASTM-A-269				10
1			-9	TUBE - 9/16 O.D. x .083 WALL	9 CR-1MO PER ASTM-A-199				9
1			-8	TUBE - .832 O.D. x .652 I.D.	↕				8
1			-7	TUBE - 1 1/2 O.D. x 1.334 I.D.	9 CR-1MO PER ASTM-A-199				7
2			-6	PIPE - 1.0 SCH 10	CRES 316 - PER ASTM-A-312				6
1			-5	BAR - 1.87 x 2.00	9 CR-1MO.-V.M. MOD. PER ASTM-A-182				5
1			-4	BAR - 1.87 x 2.00	↕				4
1			-3	BAR - 1.12 x 1.38	9 CR-1 MO-V.M. MOD. PER ASTM-A-182				3
1			-2	PLATE - 1/2 THK.	CRES 316 PER ASTM-A-240				2
			-1	ASSEMBLY					1
-1									

LIST OF MATERIALS

Mercury Boiler Tube Section - SNAP-8 Seventh-Scale Loop

V-10-1

Figure V-10 -2

167-NF-1292

NOTES:
1. REMOVE ALL BURRS & SHARP EDGES.
2. 250 ALL CUT OR MACHINED SURFACES.
3. CLEAN CRES 304 & 316 PARTS PER AGC 10319/3, METHOD V, PART (b), STEPS 1 THRU 9. DEGREASE PARTS BEFORE PICKLING.
4. CLEAN 9Cr-1Mo PARTS PER AGC 60248 PRIOR TO WELDING
5. T.I.G. WELD PER AGC-STD-1194 USING:
   a. 9Cr-1Mo FILLER ROD FOR ALL 9Cr-1Mo TO 9Cr-1Mo WELD JOINTS.
   b. 310 CRES FILLER ROD FOR ALL 9Cr-1Mo TO CRES WELD JOINTS.
   c. 316L CRES FILLER ROD FOR ALL 316 CRES TO 316 CRES WELD JOINTS
   d. 308L CRES FILLER ROD FOR ALL 304 OR 321 CRES TO 316 CRES WELD JOINTS.
6. ALL 9Cr-1Mo WELD JOINTS MUST BE PREHEATED TO 400°F MINIMUM BEFORE WELDING.
7. ALL 9Cr-1Mo WELDS SHALL BE HEAT TREATED TO 1350°F ±25°F FOR 30 MINUTES, THEN COOLED IN STILL INERT ATMOSPHERE. HEAT TREATMENT TO START AFTER WELD COOLS TO 300°F. POST HEAT TREATMENT SHALL BE IN A SUITABLE ATMOSPHERE TO GIVE BRIGHT METALLIC FINISH.
8. WELDS SHALL BE INSPECTED AFTER EACH ROOT PASS BY DYE PENETRANT METHOD PER MIL-STD-271, SECTION 5, GROUP I OR II. ANY FLAW AFFECTING THE STRUCTURAL PROPERTIES OF THE ASSEMBLY SHALL BE REPAIRED TO THE BUYERS SATISFACTION.
9. X-RAY INSPECT WELDS PER MIL-STD-453; ACCEPTANCE STANDARD PER MIL-R-11468, TABLE 1, STANDARD 1.

QTY REQD -1	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
1	V202		COM'L PROD	VALVE, ADJUSTABLE FLOW NOBBLE, ELECT. MOTOR DRIVE, #610849		FOX VALVE DEVEL. CO., INC. HANOVER, N.J.			77
1	B301		COM'L PROD	BLOWER, MODEL DRFS TYPE KS 4303, SERIES 413AS		ROTRON MFG. CO. WOODSTOCK, N.Y.			76
1	B101		COM'L PROD	BLOWER, SIZE 5E 7½ H.P. INDUCTION MOTOR 220/440V		BUFFALO FORGE CO. BUFFALO, N.Y.			75

LIST OF MATERIALS

QTY REQD -1	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
1	FE301		COM'L PROD	FLOWMETER #FM-4		MINE SAFETY APPLIANCES CO. PITTSBURGH, PENN.			74
1	FE104		COM'L PROD	FLOWMETER #FM-2		MINE SAFETY APPLIANCES CO. PITTSBURGH, PENN.			73
1	P201		COM'L PROD	PUMP, MODEL CFHT-7½		FOSTORIA CORP./CHEMPUMP DIV. HUNTINGDON VALLEY, PENN.			72
1	P101		COM'L PROD	PUMP, ELECTROMAGNETIC		GENERAL ELECTRIC SCHENECTADY, N.Y.			71
									70
									69
1	HX305		415337-1	NaK PLUGGING INDICATOR COOLER					68
1			415331-1	PIPING SPOOL #12M					67
1			415330-1	#11M					66
1			415329-1	#10M					65
1			415328-1	#9M					64
1			415327-1	#8M					63
1			415326-1	#7M					62
1			415325-1	#6M					61
1			415324-1	#5M					60
1			415323-1	#4M					59
1			415322-1	#3M					58
1			415321-1	#2M					57
1			415320-1	PIPING SPOOL #1M					56
1			415316-1	MERCURY BOILER TEST SECTION					55
1			415310-1	ANCHOR, FLOWMETER					54
1			415309-1	GUIDE, FLOWMETER					53
1			415308-1	SUPPORT, FLOWMETER					52
1			415307-1	SUPPORT (FCV201)					51
1			415306-1	GUIDE					50
1			415305-1	ANCHOR SUPPORT					49
1			415304-1	ANCHOR SUPPORT					48
1			415303-1	SUPPORT, MERCURY PUMP					47
1			415299-1	SUPPORT, MERCURY CONDENSER					46
1			415295-1	MERCURY SAMPLE STATION					45
1			415293-1	SUPPORT, NaK COOLER					44
1			415292-1	SUPPORT, NaK COLD TRAP					43
1			415290-1	PIPING SPOOL #25					42
1			415289-1	#24					41
1			415288-1	#23					40
1			415287-1	#22					39
1			415286-1	PIPING SPOOL #21					38

LIST OF MATERIALS

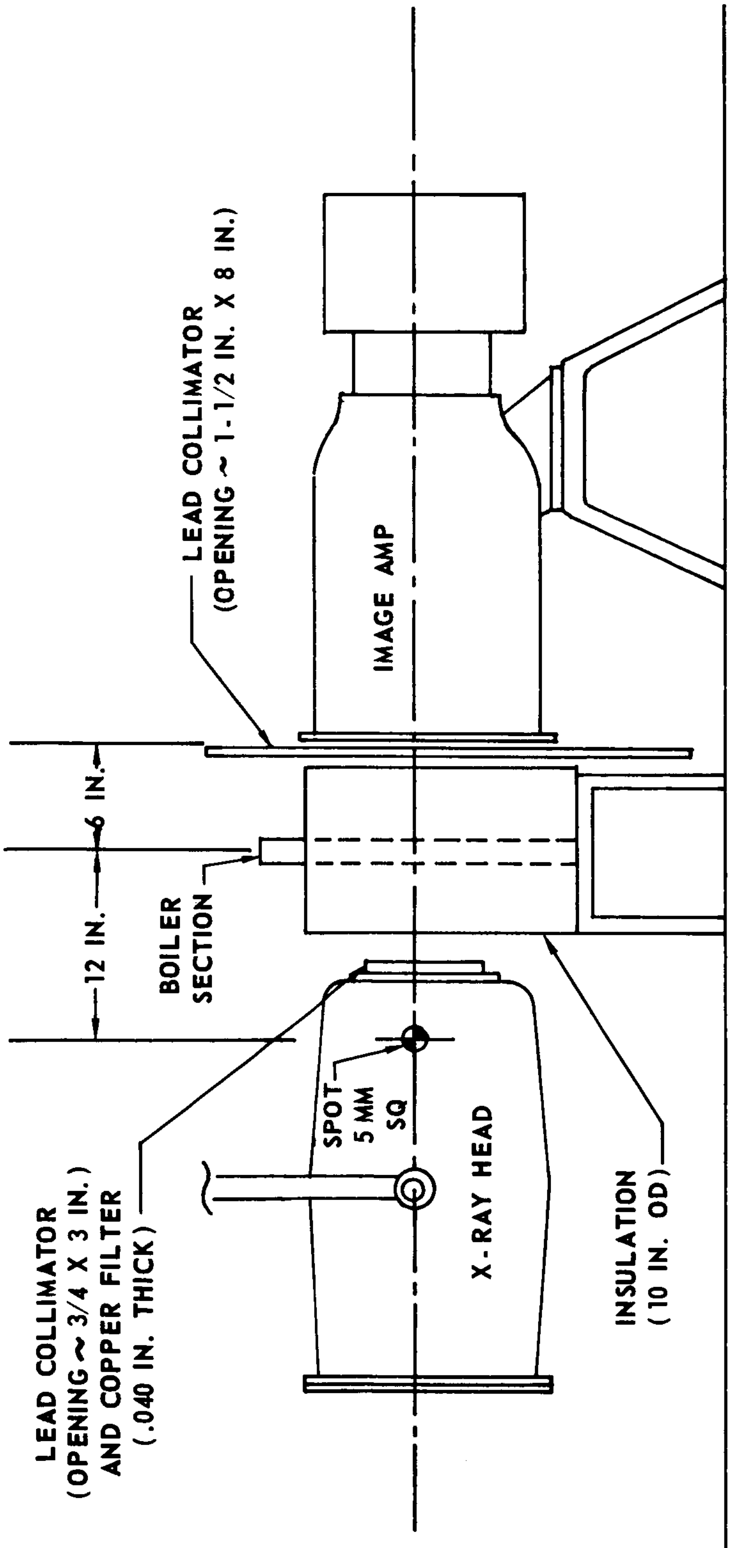
QTY REQD -1	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
1			415285-1	PIPING SPOOL #20					37
1			415284-1	#19					36
1			415283-1	#18					35
1			415282-1	#17					34
1			415281-1	#16					33
1			415280-1	#15					32
1			415279-1	#14					31
1			415278-1	#13					30
1			415277-1	#12					29
1			415276-1	#11					28
1			415275-1	#10					27
1			415274-1	#9					26
1			415273-1	#8					25
1			415272-1	#7					24
1			415271-1	#6					23
1			415270-1	#5					22
1			415269-1	#4					21
1			415268-1	#3					20
1			415267-1	#2					19
1			415266-1	PIPING SPOOL #1					18
1			415264-1	SUPPORT, Hg SURGE TANK					17
1			415261-1	SUPPORT, NaK SURGE TANK					16
1			415257-1	SUPPORT, NaK PUMP					15
1			415254-1	SUPPORT, FLOWMETER					14
1			415228-1	MERCURY BOILER, SUPERHEATER SECTION					13
1	T501		415180-1	MERCURY SURGE TANK					12
1	T-502		415179-1	MERCURY DUMP TANK					11
1	T-601		415160-1	NaK DUMP TANK					10
1	T401		415146-1	NaK SURGE TANK					9
1	FX202		415142-1	MERCURY FLOW MIXER, 4"					8
1	HX304		415140-1	NaK COLD TRAP					7
1	HE202		415138-1	MERCURY CONDENSER ASS'Y					6
1	HE101, 102 & 103		415134-1	NaK HEATER ASS'Y					5
1	HE201		415119-1	MERCURY PREHEATER ASS'Y					4
1			MF-6695-01	BOILER & TROLLEY SUPPORT ASS'Y					3
3	VX-401 VX-501 VX-601		409640-1	VAPOR TRAP					2
			-1	ASSEMBLY					1

LIST OF MATERIALS

V-9-1

SNAP-8 Seventh-Scale Loop - Parts List

Figure V-9-2

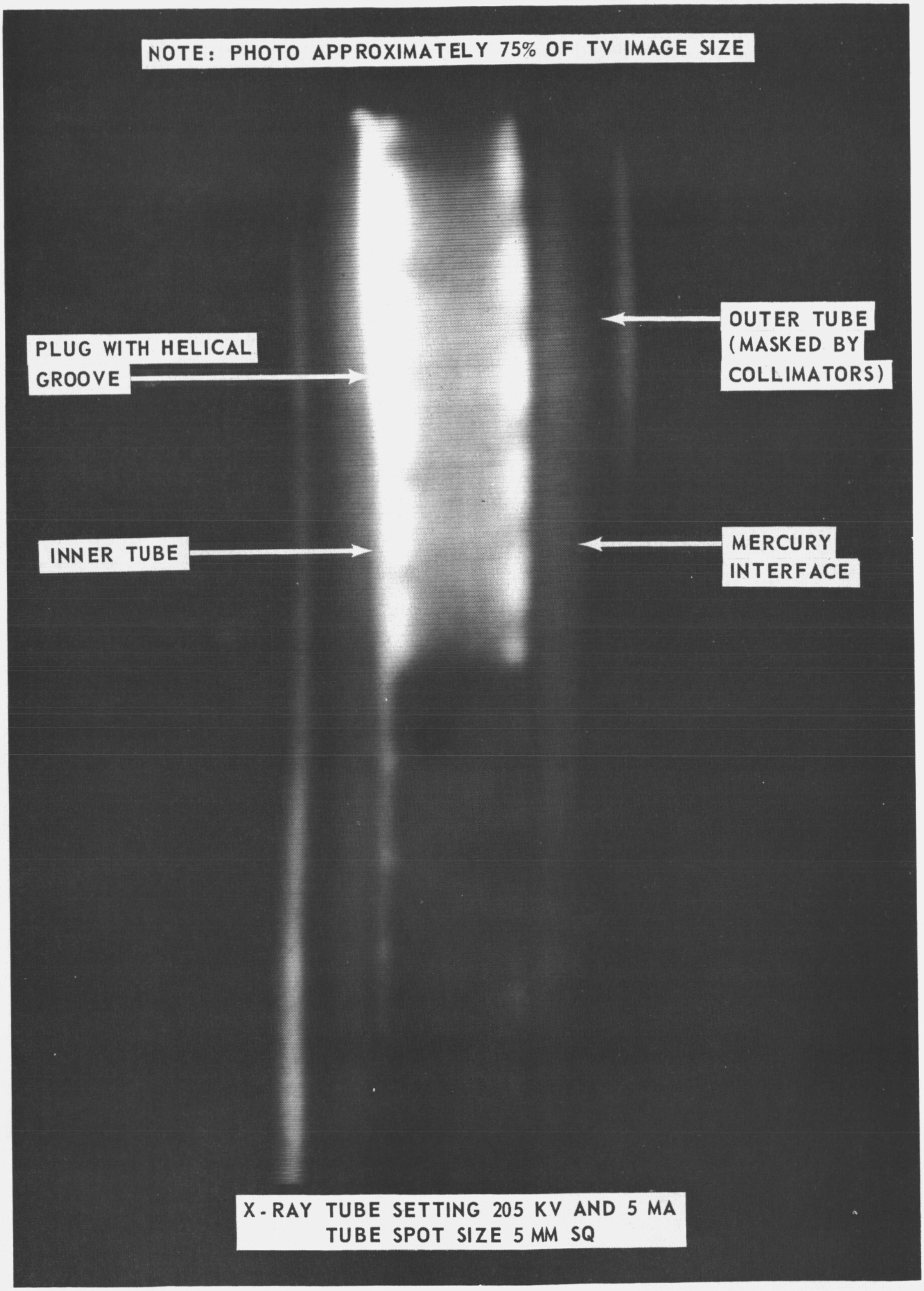


167-NF-1309

Experimental X-Ray Setup

Figure V-15

167-NF-1304



TV Image of Seventh-Scale Loop Test Specimen

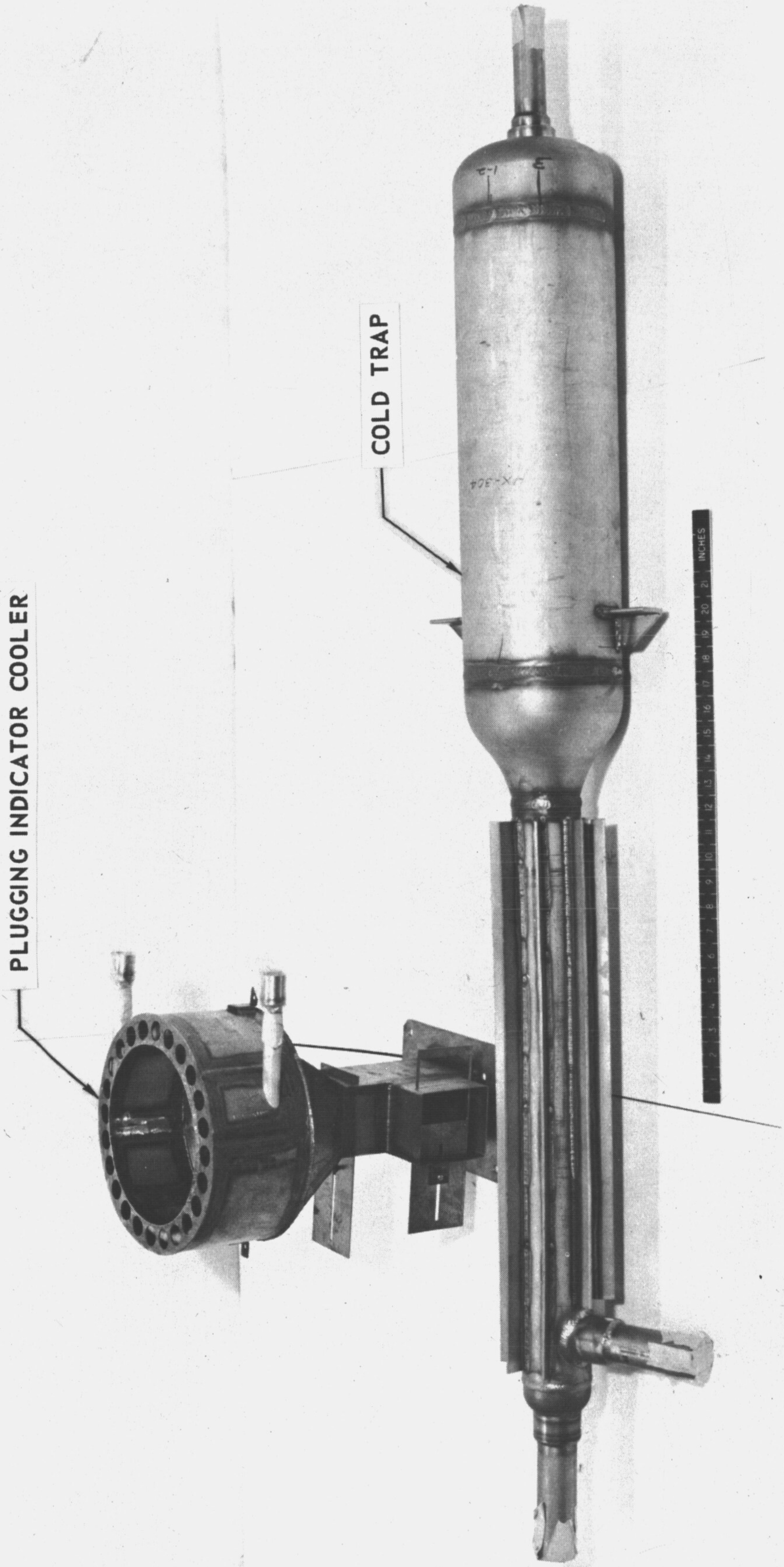
Figure V-16

167-NF-1297

NaK Heater Housing

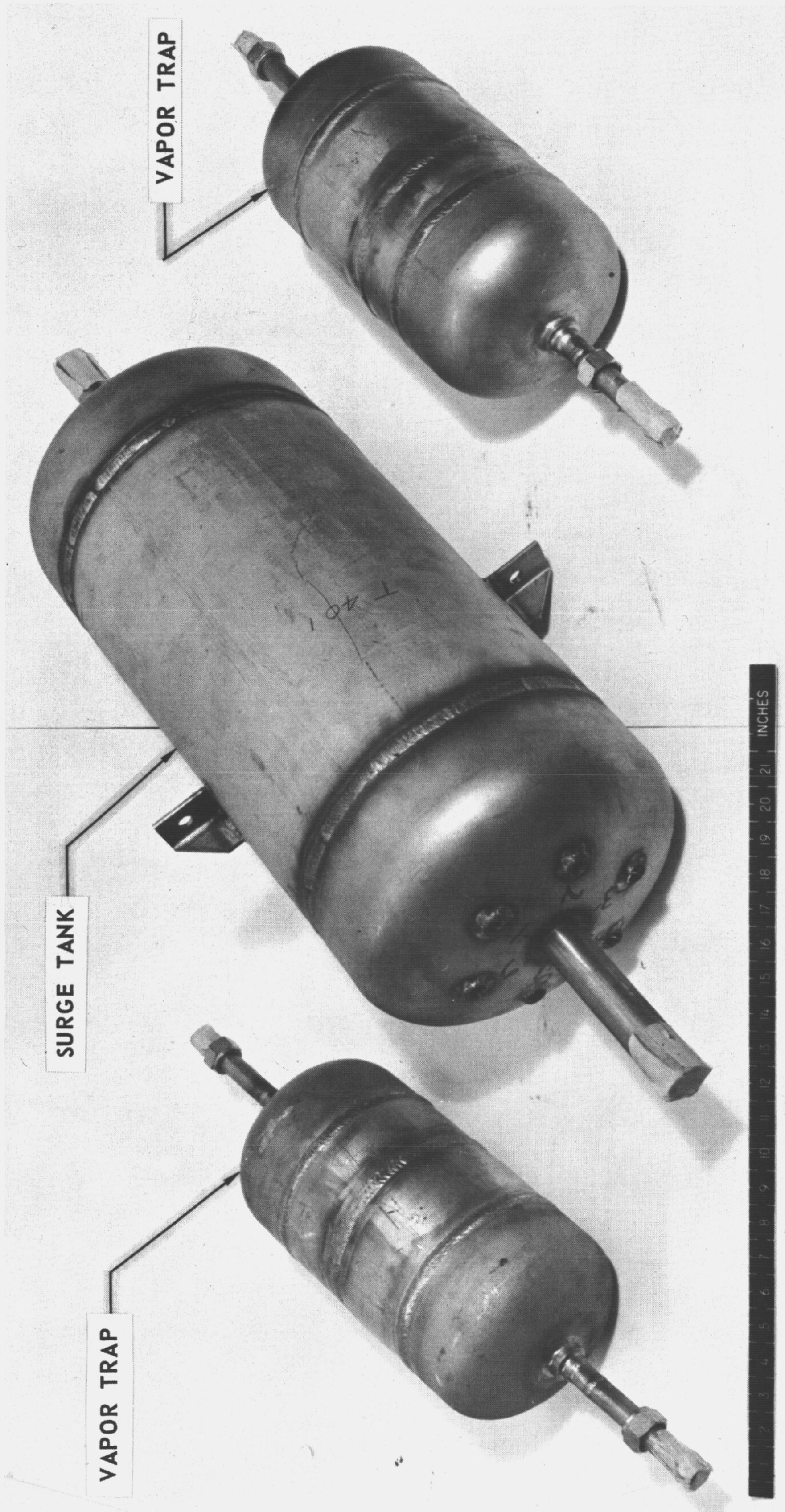
Figure V-17

167-NF-1307



NaK Purification System Components

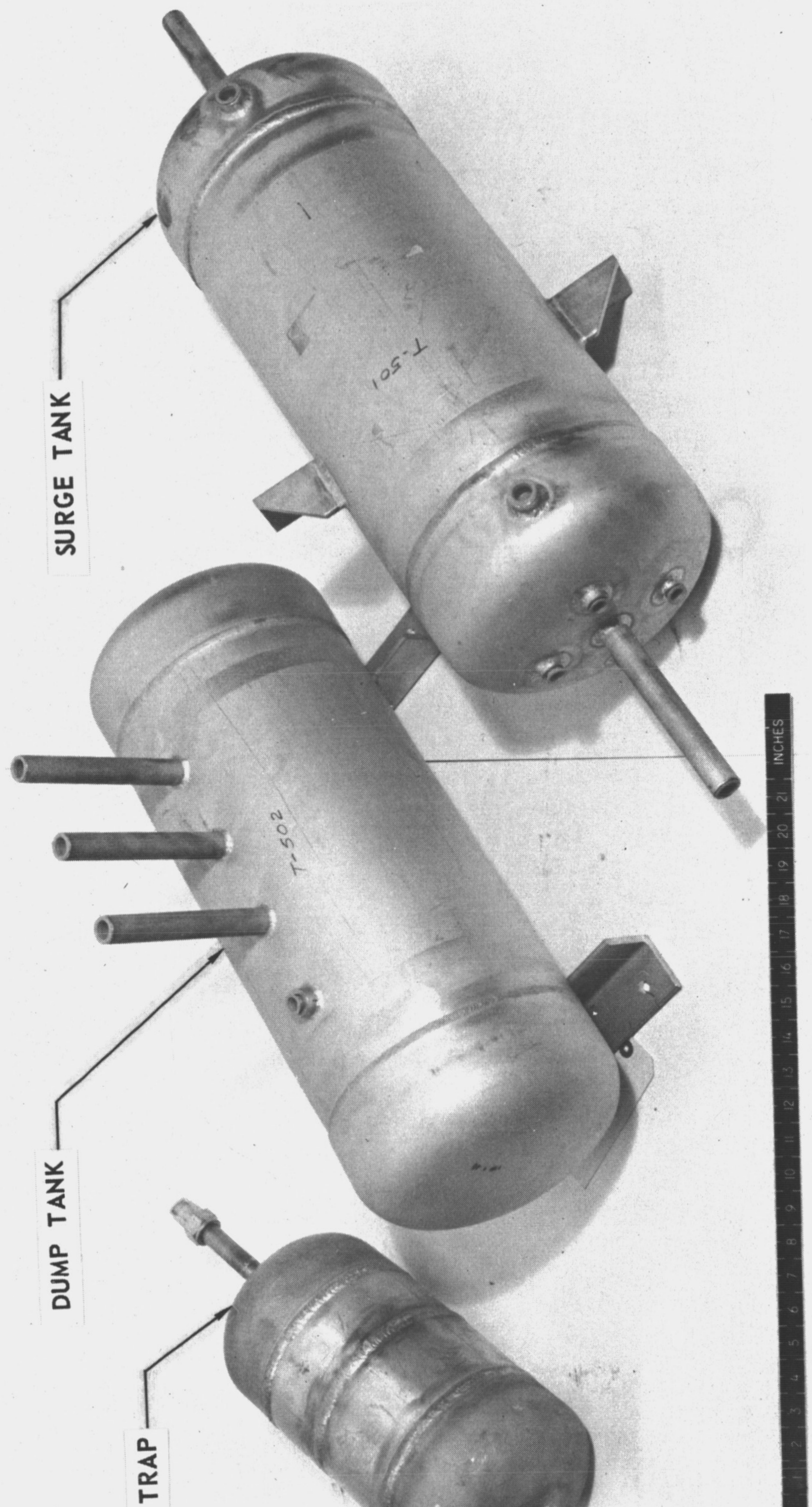
Figure V-18



NaK System Components

167-NF-1308

Figure V-19

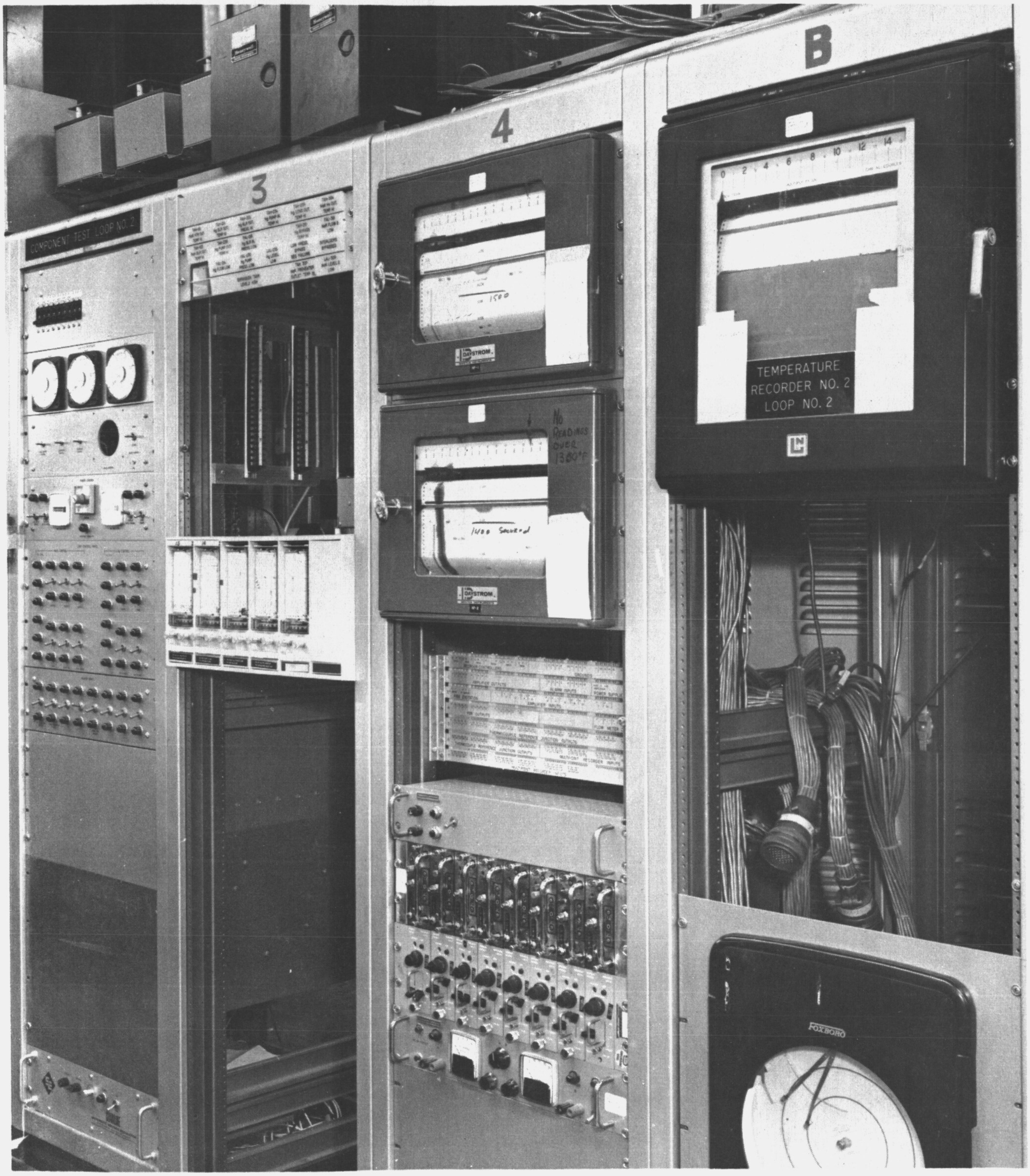


Mercury System Components

167-NF-1306

Figure V-20

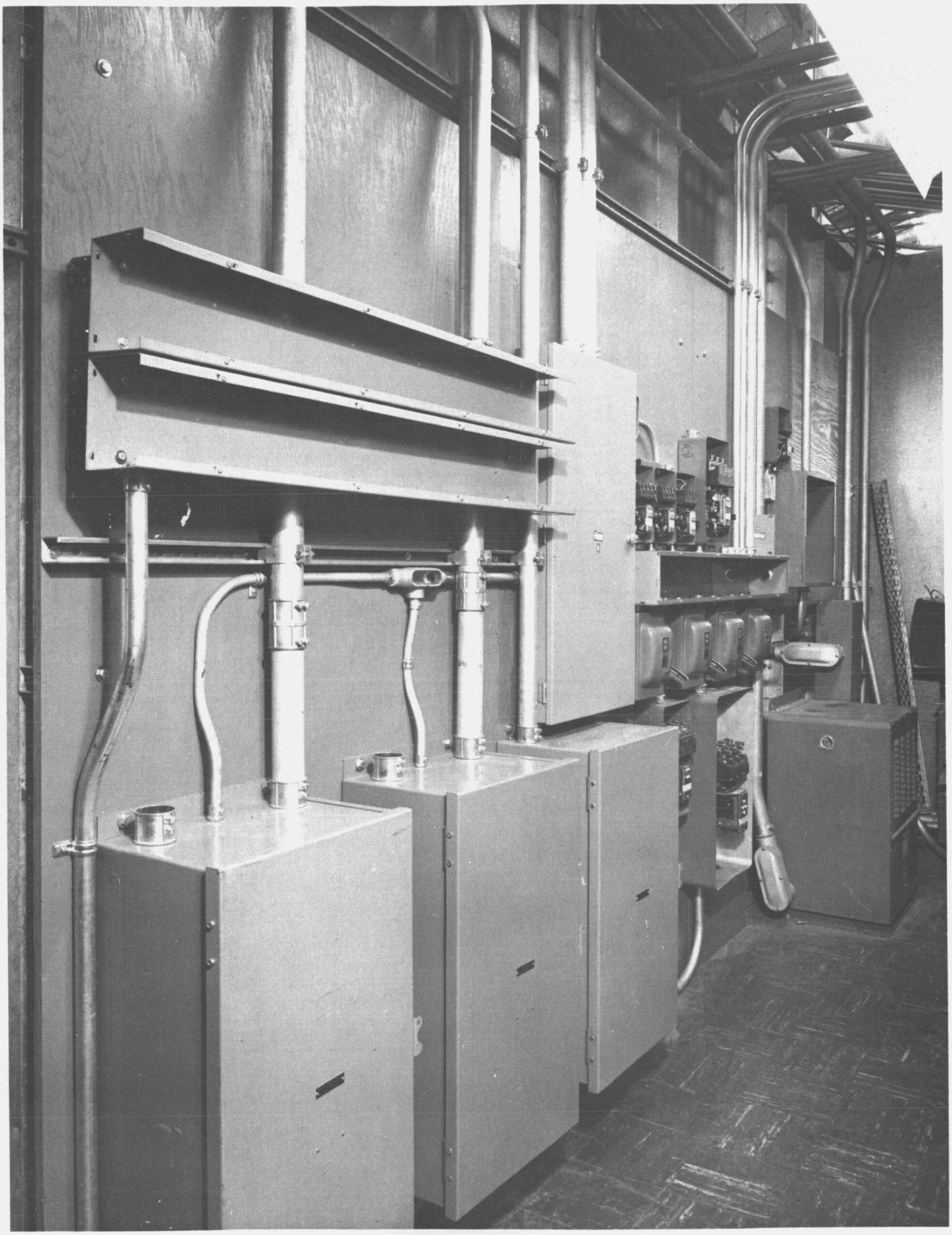
167-NF-1298



Seventh-Scale Loop Control Console

Figure V-21

167-NF-1299



Seventh-Scale Loop Electrical Controls

Figure V-22

167-012

SNAP-8 FAILURE REPORTING AND CORRECTIVE ACTION SYSTEM - FLOW CHART

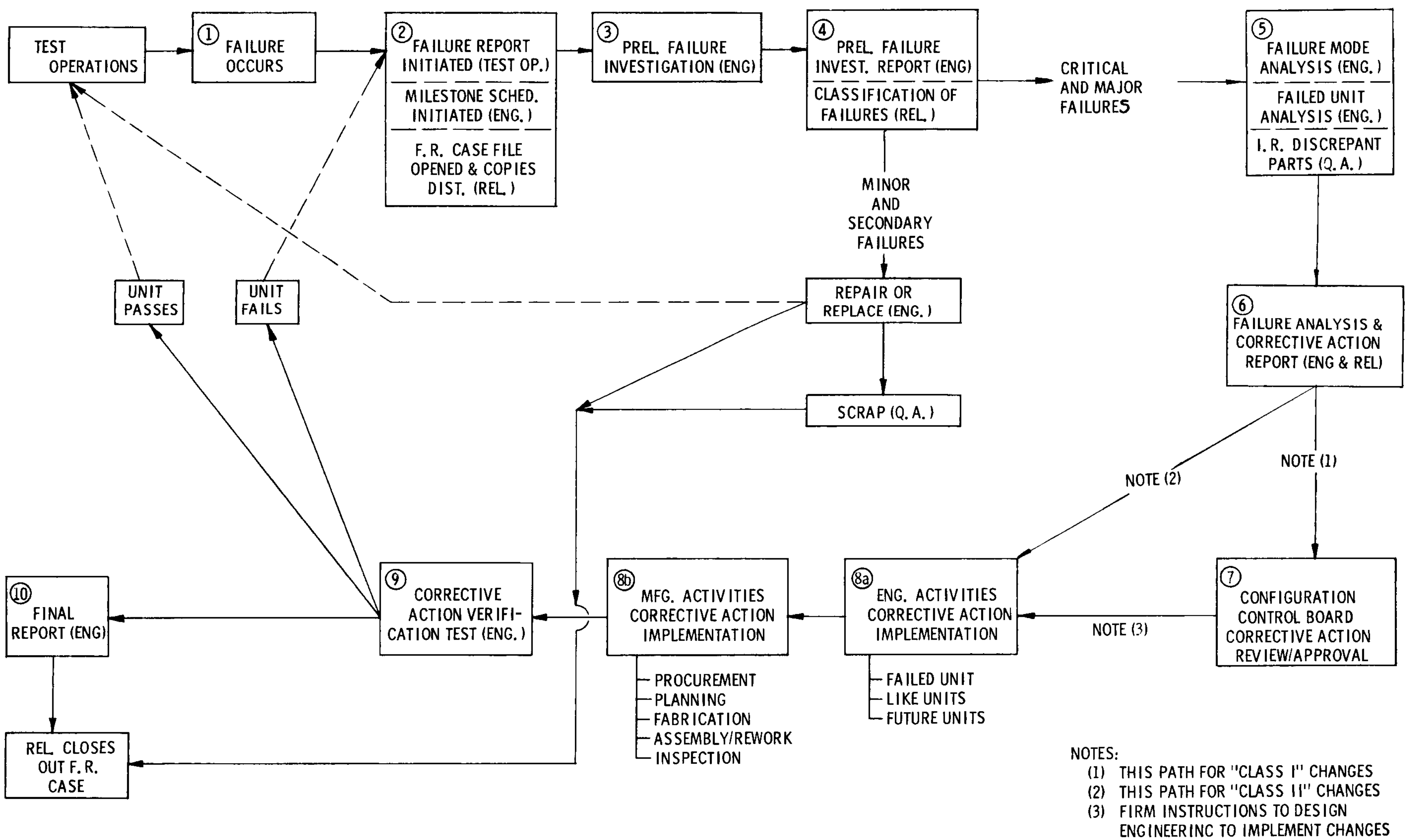
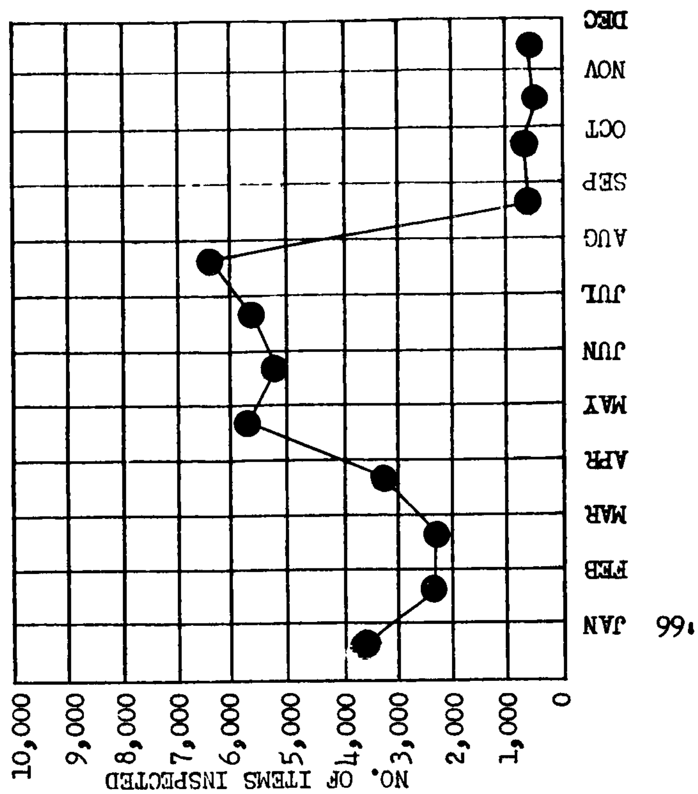
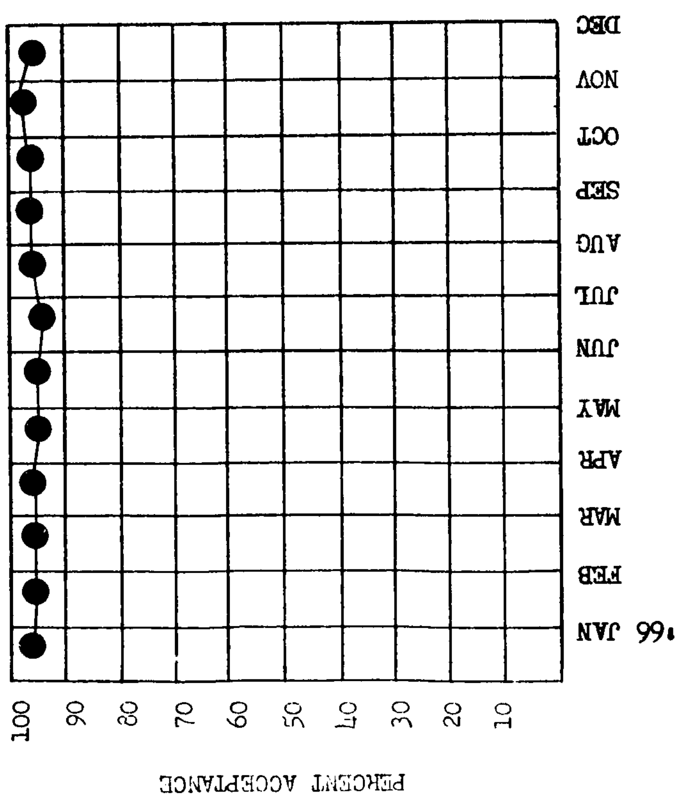


Figure V-23

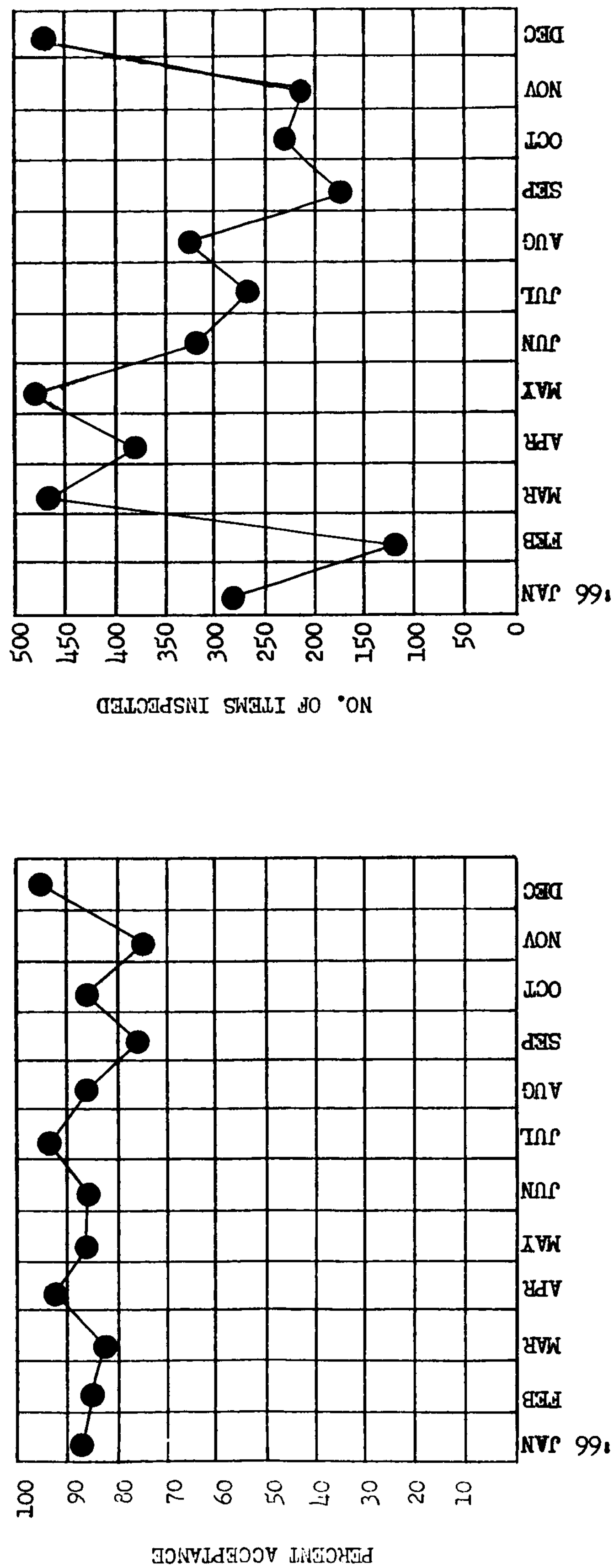




Summary of Receiving Inspection Results and Scope of Inspection

167-NF-1300

Figure V-24



Summary of In-plant Inspection Results and Scope of Inspection

167-NF-1301

Figure V-25

Report No. 3335

DISTRIBUTION LIST

	No. of Copies
National Aeronautics and Space Administration Lewis Research Center - SNAP-8 Project Office 21000 Brookpark Road Cleveland, Ohio, 44135	
Attn: H. O. Slone, Manager	2
Attn: D. G. Beremand	1
Attn: R. E. English	2
Attn: Dr. B. Lubarsky	1
Attn: S. Perrone	1
Attn: L. Rosenblum	1
Attn: Librarian	1
Attn: Space Power Systems Procurement Section	1
Headquarters National Aeronautics and Space Administration Washington, D.C., 20546	
Attn: Dr. F. Schulman (Code RNP) Program Director	1
Attn: G. C. Deutsch (Code RRM)	1
Attn: T. B. Kerr (Code RNS)	1
Attn: J. Lazar (Code RNR)	1
Attn: P. R. Miller (Code RNP)	1
Attn: W. H. Woodward (Code RN)	1
National Aeronautics and Space Administration Western Operations Office 150 Pico Blvd. Santa Monica, California, 90406	
Attn: J. S. Keeler	1
Attn: Patent Counsel	1
NASA - Azusa Field Office Room 152, Building 160 Aerojet-General Corporation Azusa, California	
Attn: J. G. Kennard	1

DISTRIBUTION LIST (cont.)

	No. of Copies
NASA - Scientific and Technical Information Facility Box 5700 Bethesda 14, Maryland	
Attn: NASA Representative	2
National Aeronautics and Space Administration Marshall Space Flight Center Huntsville, Alabama, 35812	
Attn: Dr. E. Stuhlinger	1
Attn: Claude C. Priest, R-P and VE-ANP	1
National Aeronautics and Space Administration Manned Spacecraft Center Houston 1, Texas	
Attn: Technical Information Division	2
Graham Hagey (ESDE)	1
Aerospace Corporation P. O. Box 95085 Los Angeles, California, 90045	
Attn: E. R. Berry	1
AiResearch Manufacturing Company of Arizona P. O. Box 1947 Phoenix, Arizona	
Attn: H. H. Currey Security Officer	1
Allison Division General Motors Corporation Indianapolis 6, Indiana	
Attn: T. F. Nagey	1
ASRMF-P-1 Aeronautical Systems Division Wright-Patterson AFB, Ohio	
Attn: C. H. Armbruster	1
Atomics International P. O. Box 309 Canoga Park, California	
Attn: Carl E. Johnson	5

DISTRIBUTION LIST (cont.)

	No. of Copies
The Bendix Corporation Red Bank Division Eatontown, New Jersey	1
Brookhaven National Laboratory Associated Universities, Inc. Upton, Long Island, New York Attn: Classified Documents Group	1
Director, USAF Project RAND The RAND Corporation 1700 Main Street Santa Monica, California Attn: Library VIA: Air Force Liaison Office	1
Electro-Optical Systems 300 N. Halstead Street Pasadena, California Attn: Mr. Joseph Neustein	1
Flight Propulsion Laboratory Department General Electric Company Cincinnati 15, Ohio Attn: Morris A. Zipkin	1
General Dynamics Astronautics Division San Diego, California Attn: Paul Slysh	1
General Electric Company Direct Current Motor and Generator Dept. 3001 East Lake Road Erie 1, Pennsylvania Attn: C. M. Mathias	1
General Electric Company Missiles & Space Division P. O. Box 8555 Philadelphia 1, Pennsylvania Attn: Edward Ray	1

DISTRIBUTION LIST (cont.)

	No. of Copies
Jet Propulsion Laboratories California Institute of Technology 4800 Oak Grove Drive Pasadena, California	
Attn: Donald R. Bartz	3
Attn: Librarian	1
Lockheed Missiles and Space Division Lockheed Aircraft Corporation Sunnyvale, California	
Attn: H. H. Greenfield	1
The Martin Company Nuclear Division Baltimore 3, Maryland	1
McDonnell Aircraft Corporation Advanced Engineering Missiles & Space Systems Division St. Louis 66, Missouri	
Attn: R. A. Pepping	1
Pratt & Whitney Aircraft East Hartford, Connecticut	
Attn: Wm. H. Podolny	1
Rocketdyne 6633 Canoga Avenue Canoga Park, California	
Attn: R. B. Dillaway	1
Thompson Ramo Wooldridge, Inc. 23555 Euclid Avenue Cleveland, Ohio, 44117	
Attn: E. Vargo	1
Attn: J. Picking	1
U. S. Atomic Energy Commission SNAP-8 Reactors Branch Division of Reactors Development Washington 25, D.C.	
Attn: K. Anderson	1

DISTRIBUTION LIST (cont.)

	No. of Copies
U. S. Atomic Energy Commission Canoga Park, California Attn: Mr. Carl Malmstrom	1
U. S. Atomic Energy Commission Division of Technical Information Extension P. O. Box 62 Oak Ridge, Tennessee	1
U. S. Atomic Energy Commission Oak Ridge, Tennessee Attn: A. Taboada	1
U. S. Atomic Energy Commission Germantown, Maryland Attn: Dr. J. D. Lafleur	1
USA Commander Engineer Research & Development Laboratories Support Equipment Branch Diesel and Turbine Section Fort Belvoir, Virginia Attn: J. E. Montgomery	1
Westinghouse Electric Corporation Astronuclear Laboratory Route 51 P. O. Box 10864 Large, Pennsylvania Attn: Richard C. Cunningham	1
Westinghouse Electric Corporation Box 989 Lima, Ohio Attn: R. W. Briggs	1
M. E. Talaat, Professor Mechanical Engineering University of Maryland College Park, Maryland 20740	1